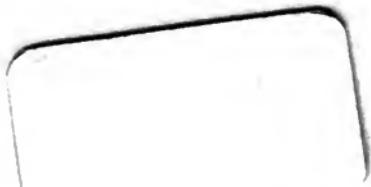


A COAL MANUAL FOR SALESMEN, BUYERS AND USERS

Francis Rawle Wadleigh



~~Bar & Beverage
King of West
Minneapolis~~



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A COAL MANUAL
for
SALESMEN, BUYERS and
USERS

By
F. R. WADLEIGH

Member American Institute Mining & Metallurgical Engineers
and
American Society for Testing Materials

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INTRODUCTION

The need of accurate elementary knowledge on the part of salesmen and users regarding coal, its origin, structure, chemistry and uses, has been demonstrated in many ways and on numerous occasions.

To supply this need, far as possible, in an elementary non-technical and practical way, is the aim of this publication.

The whole "Coal Question" is such a large one, there is so much that we have yet to learn about it, while at the same time we are adding daily to our stock of information, that merely a brief resume is attempted of our present knowledge of the subject, comprising only the more important and useful items.

The actual mining of coal will not be touched upon; its problems are technical and administrative, and consideration of them would be beyond the intended scope of this writing.

With this brief explanation of the writer's purpose and with the hope that the contents will be helpful to the coal industry and those engaged in it, this small contribution is presented to the interested public.

CHAPTER I

COAL—CIVILIZATION.

That the actual civilization of today is dependent to a large extent on the production and use of coal, is a fact not generally known or realized and may appear to be an anomaly or an exaggeration. Yet it is neither; no anomaly because it is the result of systematic study and experiment, a form of true evolution; no exaggeration when we take into consideration the vast number of processes requiring coal or dependent on its products.

To anyone who realizes the vast proportions of the coal industry, the ignorance of the average man regarding its conditions, activities and nature, is astounding. Even the daily papers, that could easily obtain accurate data, show a misunderstanding and lack of knowledge on the subject that is both ludicrous and lamentable.

Coal is the prime mover of our civilization, whether for peace or war, the substance that gives to us more useful things, more things vital to us, is more widely known, that enters more closely into the lives of civilized man than any other substance; about which we know so much and yet so little; formed when there was no sign or footstep of man, yet the real value and worth of which has only been discovered in the last few years; without which our boasted civilization would be as of the Stone Age!

Coal, as we know it, first appears on the pages of history about the time of Alexander the Great, when

Theophrastus, favorite pupil of Aristotle, in his book about stones, mentions earthy ones found in Liguria (Modern Genoa) in Northern Italy, that kindled and burned like charcoal and were used by smiths. They were called "Anthraces" or "charcoals", from their resemblance to the latter.

The beginnings of the modern coal trade, however, are found during the 13th century, when records of a more general utilization and of a regular trade in coals appear, but the modern use of coal may be said to have begun with the powerful impulse given to the iron industry about 1836, at the beginning of the Victorian era, mainly by the introduction of the hot blast as applied to iron furnaces.

Since that time the output of coal and the growing number of uses to which it or its derivatives are and have been put, have kept pace with population and civilization, until now we not only get light, power and heat from coal but an ever increasing number of substances most necessary to our comfort and health, some of which had been obtained from natural sources, but many of which are new to us; beautiful dyes, delicate flavors, the fragrance of flowers, the most powerful drugs, material for modern explosives, antiseptics and disinfectants, roofing material, road pavement and building material, oils of various kinds, fertilizers, besides many other substances, commercial uses for which have not yet been discovered.

"There's hardly a thing that a man can name
Of use or beauty in life's small game
But you can extract in alembic or jar;
Oil and ointment and wax and wine
And the lovely colors called aniline;
You can make everything, from a salve to a star
If you only know how, from black coal tar."

—“Punch.”

COAL, ITS PRINCIPAL USES

As Fuel—For Power-making

- Locomotives
- Steamships
- Steam Power Plants
- Gas Producers

Heating and Lighting

- House use
- Heating Plants
- Lighting Plants

Manufacturing and Metallurgical Processes, Heating, Boiling, Drying, Melting

- Manufacture of Textiles
- Manufacture of Paper
- Lumber Drying
- Brick, Tile and Pottery Manufacture
- Cement Making
- Glass Making
- Smelting and Refining of Metals
- Abrasives and Lubricants

Carbonization and By-Product Industries

- Coke Manufacture
- Gas for Power, Heating and Illuminating
- By-Products—Ammonium Sulphate, Chloride and carbonate
- Tar—from which
 - Pitch
 - Motor Fuels
 - Dyes
 - Oils, Fuel and Lubricating
 - Paints and Varnishes
 - Medicines
 - Disinfectants and Antiseptics

Perfumes and Extracts
Roofing and Paving Materials
Explosives
Acids and Solvents
Wood-preserving Materials
Chemical Processes, Materials for.

What Is Coal?

"Our knowledge of the actual constituent bodies of coal is very slight." (Brame). We do not know the exact constitution of the chemical changes and reactions involved in its formation and nature; even the geological and chemical processes it has been subjected to in process of formation are still disputed. That its original source was vegetable matter is about the only universally accepted theory regarding its origin.

An exact definition is difficult to formulate, but in a geologic sense, coal is a carbonaceous rock, not a mineral, belonging to the group of sedimentary rocks, formed in different ways, under different conditions, from different accumulations of vegetable matter.

A seam of coal represents but one of a geological sequence of rocks, which must be studied as a whole if we are to understand the circumstances of its formation.

That the "mother substance" of coal consisted of vegetable matter is now a universally accepted conclusion. But as to how this substance has been transformed into coal, as we know it today, there are several different theories, each one of which may be right as to some particular coal formation. In other words, each coal seam has its own problems and its exact method of formation may differ from that of another seam.

"Coal represents the accumulation of solar energy, fixed by luxurious forest growths in carboniferous and

other geological ages, over almost incredible periods of time." (Harger).

Coal, then, is a carbonaceous rock of complex and varying nature, its origin vegetable matter, altered by various geological and chemical processes to form coal as it exists today. Its exact chemical constitution we do not know, possibly we never will know, notwithstanding the great number of researches that have been and are being made by both chemists and geologists.

"Ordinary coal is a compact stratified mass of mummified plants (which have in part suffered arrested decay to varying degrees of completeness) free from all save a very low percentage of other matter."

This definition of coal is given by Dr. Marie E. Stopes Dr. R. V. Wheeler in a paper on "The Constitution of Coal" read before the British Society of Chemical Industry in 1918; both of the authors are well-known British chemists and investigators. They state that they have found no satisfactory definition of coal and offer the one just given, stating, however, that "it will be very easy to criticise it."

Origin of Coal.

To go into a detailed discussion as to the origin and constitution of coal would require a volume by itself and would not serve the purpose for which this pamphlet is intended; let us close any discussion of the subject with the following, generally accepted as proved facts.

Coal consists of many varieties; statements of origin and formation that may be true of one kind of coal do not always or necessarily hold good for any other kind.

Different original vegetable substances may finally result in the same kind of coal, while the same original substances may result in widely differing classes of coal;

final differences being due to variations in the geological and chemical influences to which the original substance has been subjected.

Final Definition of Coal.

Coal is a mixture of chemical compounds, the nature of the individual compounds and the proportions in which they occur in the various coals, depending upon the nature of the material from which the coals have been derived and upon the subsequent changes in chemical and physical conditions it has undergone in geological time.

Classification of Coals.

The problem of finding a system of coal classification that will fit all kinds and classes of coal has given rise to a great deal of discussion, and a number of systems have been suggested, none of which have been universally accepted; of the schemes that have been offered, most are based entirely on chemical composition, but none of them are entirely satisfactory, nor do they cover the ground without exceptions.

For the coals of this country (and the system will apply as well to the coals of foreign countries), it is probable that the general classification finally adopted by the U. S. Geological Survey is of greater practical value, is less elaborate and covers better the entire range of coals, than any other plan yet suggested.

One great difficulty in finding a classification that will fit all cases, is the fact that there is no sharp line of demarcation between the different coals and that the chemical characteristics of one kind of coal overlap those of another, so that physical differences have to be considered, as well as chemical.

For our purpose, therefore, and without going into any detailed discussion of the question, the general classifica-

tion, as adopted by the Geological Survey, is given, as the most practical solution of the problem, as far as this country is concerned, following, as it does more or less closely, the common trade classifications.

The Survey classification uses the term "Rank" instead of "Classes", as more properly denoting the different kinds of coal, and as distinguished from the different grades, the latter term applying to coals of differing degrees of purity but not necessarily of different rank or class.

Rank	Description
Anthracite	Fuel ratio, not more than 60 not less than 10.
Semi-anthracite	Fuel ratio from 6 to 10.
Semi-bituminous	Fuel ratio, maximum 3.
Sub-bituminous	Black in color as distinguished from "Black lignite" lignite and with no woody structure. Differing from bituminous in its great loss of moisture and slackening when exposed to alternate drying and wetting.
Lignite	Brown in color and distinctly showing a structure like wood or having an appearance like clay.

Under each of the ranks just given we find different varieties of coal, sometimes described according to their use, sometimes according to some difference in structure or fracture. These varieties overlap each other; some coals are well-adapted for more than one use, as the following brief outline will show.

Anthracite.

Hard coals, all of the same general character, differing in the degree of hardness and in fracture and, to a small

extent, in percentage of volatile matter; the Welsh anthracite will average from 5 to 8 per cent, the Pennsylvania from 4 to 6.

The different sizes of anthracite show great variations in ash content, due to the varying amounts of impurities they contain.

Semi-Anthracite.

Hard coal, but softer than anthracite; usually contains from 7 to 12 per cent volatile matter. This class is of small importance in this country, and is of rare occurrence, being represented principally by the Bernice Basin Coals of Pennsylvania, the Montgomery, Pulaski and Wythe County fields of Virginia and the semi-anthracite of the Spadra district of Arkansas.

Semi-Bituminous.

In this rank are included, the "low volatile, smokeless" steam coals of Virginia, West Virginia, Pennsylvania and Maryland, with the Arkansas coals of the Jenny Lind and Huntington districts of Arkansas, and a few comparatively small districts in Washington (Wilkeson & Fairfax), Utah (Kane Co.), Oklahoma (Haskell & LeFlore Counties) together with a very limited area in Northern Alabama and Georgia.

Among the semi-bituminous coals are the well-known Pocahontas-New River coals of West Virginia, the Georges Creek of Maryland and the steam coals of Cambria, Clearfield and Somerset Counties, in Pennsylvania.

The best semi-bituminous coals have higher heating value than any other coals in the world and are on that account, the world's best steam coals.

Besides the United States coals mentioned (the highest grades in this country) the famous Welsh steam coals of

Great Britain are also in this rank, although they differ quite a little in structure and fracture from the United States semi-bituminous coals, being less friable and with more of a conchoidal fracture.

According to the commonly used trade classification, the semi-bituminous coals contain from 12 to 25 percent volatile matter. Besides being excellent steam coals, some of them are also good coking coals, much used for that purpose, usually mixed with a large percentage of bituminous coals, when coked in by-product ovens; their use in beehive ovens is gradually being discontinued.

Bituminous Coals.

This class or rank is a very large one and contains many varieties, that differ not only in chemical content, but also in appearance, structure and in suitability for different uses.

Included in this class of coals are,—

Coking coals

Gas coals

Steam coals

House or domestic coals

Cannel coal

Splint coals (referring to fracture).

According to the usual trade classification, bituminous coal ranges from 25 to 40 per cent (or more) volatile matter, with varying amounts of other constituents, with a wide range in heating value and with great variation in friability and other physical characteristics.

Bituminous coals are softer than anthracite coal (hence the term "soft coal"), but usually harder than the semi-bituminous coals; the line of demarcation between the coal of bituminous rank and those of lower rank is not an exact one, the distinguishing feature being the dif-

ferent way in which they are affected by exposure to the air, as well as the higher moisture and oxygen content of the low rank coals.

Although often attempted, no generally satisfactory classification of bituminous coals has ever been made; the simplest and one commonly used in the trade divides them into medium volatile, 25 to 30 per cent, and high volatile, over 30 per cent. Probably the most generally used classification in this country and in Great Britain is one based on the different uses to which the coals are put. In France and other European countries, however, a classification is largely used, based mainly on the way in which the coals act when burned, together with the percentage of volatile matter in each.

This general classification, devised by M. Gruner, is as follows:

1. Non-coking coals, long flame.
2. Coking coals, long flame, gas coals.
3. Bituminous furnace coals, yellowish flame, melt when heated.
4. Coking coals, short flame, cake moderately; yield a hard coke.
5. Anthracite coals; do not break up in fire, short flame, little smoke, do not cake when heated.

The French and Belgian trade classifications are based on the Gruner scheme, modified and enlarged to cover varieties of use.

Sub-Bituminous.

This rank of coal has been so described by the United States Geological Survey, in place of the old term, "black lignite" under which coals of this class were formerly classified.

Sub-bituminous coals are distinguished from lignite by their color, black, as against brown, and by their fracture

and structure, the latter having a marked "woody" appearance.

As distinguished from bituminous coals, the difference is less well defined and is mainly the difference in loss of moisture and "slacking", when exposed to weathering.

Some of the sub-bituminous coals are of good quality, quite equal to the inferior bituminous varieties.

Lignite.

This term, as used by the United States Survey, "is restricted to those coals which are distinctly brown and either markedly woody or claylike in their appearance. They are intermediate in quality and in development between peat and sub-bituminous coal." (United States Geological Survey, Bull. 100).

Lignite will not stand either storage or transportation, as it is liable to ignite spontaneously, slacks and loses heating power when exposed to weather and breaks readily; it must, therefore, in its raw state, be used near the mines.

It bids, however, to become a most useful fuel, as of late years, experiments have proved that it will make excellent briquettes and if carbonized, will give large yields of oil and other by-products.

Both the Canadian Department of Mines and our own Bureau are actively investigating the possibilities of lignite utilization along the lines just mentioned, while in Germany, Austria and France (to some extent) the possibilities of lignite have long been made commercially effective, especially as regards briquette production. Before the war, Germany's yearly output of brown coal briquettes was 21,418,000 metric tons.

The success of low temperature carbonization will greatly enhance the value of our lignite deposits. (See description of this process under "Coke".)

CHAPTER II

COAL FIELDS OF THE WORLD.

Coal is found in varying amounts, in different geologic measures and of different qualities, in nearly every country in the World.

Of the six great subdivisions or continents, North America, as far as known today, contains the greatest amount and the greatest variety of coals, although a more accurate knowledge than we have now of the coal fields of Asia, may change this statement.

The following tabulation estimates the World's coal resources or "Reserves" and is based mainly on a report on "The World's Coal Resources", issued in 1913, under authority of the International Geological Congress; some later figures have been given where the authority seemed reliable. The estimates for a number of countries are admittedly based on scant actual knowledge and are at best no more than educated guesses; especially is this the case as regards South American countries, where little prospecting has yet been done and where there are thousands on thousands of square miles that no white man has ever seen.

The estimate for Venezuela, for instance, includes only one property; that for Columbia takes in only one district, (some fifteen districts are known to contain coal) and is based on no more data than a few seam outcrop measurements in the foothills of the Western Cordilleras and the probability that the coal seams or beds flatten out and underlie the valley at the foot of the hills.

Estimated Coal Reserves of the Principal Coal Producing Countries of the World.

	Estimated Coal Reserves	Remarks
North America		
Canada	1,234,000,000,000	International Geological Congress 1918
United States	3,538,664,000,000	U. S. Geological Survey, 1917
South America		
Chile	No estimate, data insufficient	
Europe		
Great Britain	197,000,000,000	By H. S. Jevons, 1915
France	17,584,000,000	1913, I. G. C.
Germany	428,356,000,000	1913, I. G. C.
Belgium	11,000,000,000	1913, I. G. C.
Holland	4,402,851,000	1913, I. G. C.
Russia	60,106,000,000	1913, I. G. C.
Spain	8,768,000,000	1913, I. G. C.
Austria	63,876,200,000	1913, I. G. C.
Hungary	1,716,702,000	1913, I. G. C.
Poland	94,330,000,000	Polish Government, 1918
Czecho-Slovakia	No estimate	
Asia		
China	1,500,000,000,000	1913, I. G. C. Data insufficient for statis. estim't
Japan	8,792,000,000	1920 Japanese Government
India	79,001,000,000	1913, Department of Mines
Indo-China	20,000,000,000	1913, I. G. C.
Africa		
Union of South Africa	56,200,000,000	1915, Government estimate
Australia		
Australia	165,572,000,000	1913, I. G. C.
New Zealand	2,358,000,000	1913, Government Reports

Other Countries, With Known Coal Reserves and Limited Production. No Satisfactory Estimates of Tonnage Can Be Made on Account of Insufficient Data.

North America				
Greenland	---	Unimportant deposits	Unimportant deposits	Data insufficient for satisfactory estimate
Alaska	---	16,293,000,000	16,293,000,000	Mexico—No estimates, deposits large
Mexico	---	---	---	---
South America	---	---	---	---
Columbia	---	27,000,000,000	27,000,000,000	Venezuela—No estimate, deposits large
Venezuela	---	---	---	Ecuador—No est., deposits small probably
Ecuador	---	---	---	Peru—No estimate, deposits large
Peru	---	---	---	Brazil—No est., probably large deposits
Brazil	---	---	---	Argentina—No est., probably sm. deposits
Argentina	---	---	---	---
Europe				
Sweden		114,747,000	114,747,000	Deposits unimportant
Denmark	---	50,000,000	50,000,000	Deposits unimportant
Portugal	---	20,550,000	20,550,000	Deposits unimportant
Spitzenberg	---	8,750,000,000	8,750,000,000	1. G. C. 1913, data incomplete
Italy	---	243,450,000	243,450,000	1. G. C. 1913
Greece	---	30,000,000	30,000,000	Satisfactory data not available
Serbia	---	52,750,000	52,750,000	1. G. C. 1913
Turkey	---	387,650,000	387,650,000	Satisfactory data not available
Bulgaria	---	36,000,000	36,000,000	1. G. C. 1913
Romania	---	---	---	Data Available Not Complete
Africa				
Algeria	---	---	---	Data insufficient for estimate
Nigeria	---	---	---	Data insufficient for estimate
Madagascar	---	---	---	Data insufficient for estimate
Rhodesia North & S.	---	6,368,000,000	6,368,000,000	1913, I. G. C. and S. A. Min. & Eng. Journal
Congo, Belgium	---	9,990,000,000	9,990,000,000	1918, I. G. C. Data insufficient
Asia				
Manchuria	---	1,209,000,000	1,209,000,000	1913, I. G. C.
Korea	---	81,000,000	81,000,000	---
Formosa	---	461,000,000	461,000,000	Estimate by Japanese Government
Russia	---	178,979,000,000	178,979,000,000	1918 I. G. C. Insufficient data
East Indies	---	No est., large known dep.	No est., large known dep.	---
Persia	---	1,858,000,000	1,858,000,000	1913, I. G. C.
		Note.—(I. G. C.) International Geologic Congress.		

COAL FIELDS OF THE UNITED STATES

The United States of America contain the greatest known coal fields of the world, carrying all kinds and grades of coal, from the lowest grade of lignite to the best grade of semi-bituminous steam coals, as well as anthracite and semi-anthracite.

Of the 48 States, 32 contain deposits of coal of some description, as the following tabulation will show:

No coal deposits found in

Maine	South Carolina
Massachusetts	Florida
New Hampshire	Arizona
Vermont	Minnesota
Connecticut	Delaware
New York	New Jersey
Mississippi	Wisconsin
Louisiana	Nebraska

Coal deposits found in

Rhode Island	Missouri
Pennsylvania	Texas
Maryland	Oklahoma
Virginia	Kansas
West Virginia	North Dakota
North Carolina	South Dakota
Georgia	Montana
Alabama	Wyoming
Kentucky	Idaho
Tennessee	Colorado
Ohio	New Mexico
Indiana	California
Michigan	Oregon
Illinois	Washington
Iowa	Nevada

Coal Provinces

The U. S. Geological Survey has divided the U. S. Coal Fields into six great regions or "Provinces"—(the term used by the Survey). They are:

1. The Eastern Province.

This coal province contains about "nine tenths of the high-rank coals of the country." (U. S. G. S. Bull 100). It includes the anthracite regions of Rhode Island and Pennsylvania, the Atlantic Coast region and the great Appalachian region, the latter embracing both bituminous and semi-bituminous coal of the highest rank, extending from Pittsburgh, Penna., into Alabama.

2. The Interior Province.

This province includes all the fields near the Lakes, the Mississippi Valley fields and the Texas field, comprising four great regions.

Northern—	Michigan
Eastern—	Illinois
	Indiana
	West Kentucky
Western—	Iowa
	Missouri
	Kansas
	Oklahoma
	Arkansas
Southwestern—	Texas

The coals of this province are all bituminous, with the exception of the semi-anthracite of Arkansas; while not of as good quality as those of the Eastern province, the extent of the fields and the abundance of coal, with good mining conditions, together with close proximity to large markets, have made a wonderful development and a very large output, comprising some of the largest producing mines in the world.

3. The Gulf Province.

Of small importance and containing only lignite with its only commercial development in Texas.

4. Northern Great Plains Province.

This includes all of the coal fields of the Great Plains east of the Eastern front of the Rocky Mountains.

While covering a great area, with a tremendous tonnage of coal, the coals themselves are generally inferior to those of the more eastern provinces (except the Gulf Province and development is not so extensive.

In rank, the coals range from lignite to bituminous of fair quality.

5. The Rocky Mountain Province.

While of comparatively recent development, this province contains some quite high grade coals, notably in Colorado and Utah, Wyoming and New Mexico and every variety of coal known, from lignite to anthracite, although the greater part of the coals found are low grade bituminous and sub-bituminous.

The greatest development in this province is found in Colorado, New Mexico, Utah, Wyoming and Montana.

6. The Pacific Coast Province.

Nearly all of the coal in this province is found in the State of Washington, although California and Oregon contain several small fields of little importance today, either in size or quality of coals.

Some of the Washington coals are high rank bituminous with some semi-bituminous coking coal, down to lignite.

In giving an estimate of the unmined coals of the United States the figures of the U. S. Geological Survey have been followed as being the most accurate and authoritative.

CHAPTER III. THE PURCHASE OF COAL

The Buyer

The coal buyer, whatever may be his title, is not capable of purchasing coal to the best advantage of his company unless he has a practical working knowledge of certain important items, summarized as follows:

1. Kind of Coal.

The kind of coal best suited to the equipment and conditions under which it is to be used.

2. Prices.

The market prices of the coals available at his plant.

3. Analysis.

A knowledge of coal chemistry sufficient to enable him to know what the analysis of coal means and what it should tell him about coal offered.

4. Character and Quality.

A knowledge of the character and quality of the coals that are sold in his market, so that he may be able to tell (1) which coal is suitable for his purpose (2) whether the seller is misrepresenting the character and quality of his coal.

5. Source of Coal.

He should know or ascertain the reliability of the seller and whether the mine or mines from which coal is offered are able to produce the kind and tonnage of coal so offered.

6. Transportation Rates.

He should know the freight rates on all coals that are sold in his particular market.

7. Combustion and Use.

He should have a sufficient knowledge of combustion, conditions of use and firing to be able to form an intelligent opinion as to whether coal is being properly handled at his plant or plants or on his railroads. In this connection it would be entirely advisable to consult his Chief Engineer or the man who has direct charge of the use of the coal bought, as to the suitability of the various coals, results that are being obtained, etc.

8. Storage.

He should be well-informed as to coal storage in general, cost of rehandling, storage methods, &c.

9. Plant Consumption.

He should have accurate current knowledge of coal consumption and the results obtained in everyday use.

This may seem a rather formidable list of requirements for the coal buyer, but they are readily acquired and are necessary for the intelligent purchase of coal.

The lack of accurate elementary knowledge of coal on the part of both buyer and seller has often been commented upon and is pretty well known; nevertheless, few companies, either those mining and selling coal or those using coal, make any systematic effort to have either salesmen or purchaser obtain accurate information regarding the substance they are handling.

The Seller.

The seller of coal has just as great a need of certain items of knowledge about coal, its chemistry and use, as the buyer has.

The salesman or sales manager should acquire or should have a knowledge of the following general items:

1. Source and Preparation.

He should know how his coal is mined and prepared,

the general character of the seams or beds it comes from and the capacity of the mines as regards production.

2. Character and Quality.

He should have sufficient reliable and accurate knowledge of the character and quality of his coals and the uses they are suited for.

3. Analyses.

He should know the meaning of coal analyses and what they should tell.

4. Impurities.

He should know what impurities are found in coal and be able to detect them with some degree of certainty.

5. Transportation.

He should be thoroughly informed as to distance and freight rates in his territory.

6. Competitors.

He should know as much about his competitor's coals as he does about his own.

Methods of Purchase.

In general, there are two methods of purchasing coal.

1. On its name, general character and reputation, depending largely on the honesty and reliability of the seller.

2. By specification, based on analysis and heating value determination.

The first method, with various modifications, is the one in most general use today and probably will be for sometime to come; it has weathered many storms of criticism and is capable of good service and results, under intelligent handling; it is also the refuge of the ignorant buyer, generally the smaller user. Under this plain, each buyer and seller has his own adaptation of purchase

methods, but the items given in the foregoing suggested requirements, are quite as useful to both sides, no matter what method is adopted.

Purchase of Coal On A Specification Basis.

The purchase of coal on a specification basis has been a practice of comparatively recent date. The first large contract for coal placed under this method was, as far as known, that of the Illinois Maintenance Co. in 1902, for 20,000 tons on a B. t. u.-ash-moisture basis, but the Interboro Company of New York, was probably the first large consumer to contract for all of its coal on a strictly specification basis, with premium and penalties, this company having put such a contract into effect about 1907.

In 1914, it was estimated that some ten or twelve million tons were bought in this country on specification, and the use of the method was growing, although there was also strong opposition to its use on the part of many coal operators and selling agencies. Since the beginning of the war, the use of this plan has been in a great measure discontinued, owing to conditions of supply and demand brought on by the war.

Advantages of the Specification Method of Purchase.

"There are few materials required in our manufacturing and carrying industries which are purchased on a large scale with such a neglect of common-sense rules and precaution, as fuels. The majority of our manufacturers still purchase fuel by this rule-of-thumb method, which satisfied the last generation. A user is not purchasing so many tons of a solid uniform composition, but should

be purchasing so many units of heat in solid form, as a matter of convenience."

The principal arguments in favor of this system of coal purchase, may be summed up as follows:

1. It places all sellers on a similar competitive basis as regards both quality and price.
2. It enables more sellers to compete by eliminating trade names and districts, thus broadening competition.
3. Systematic and current analyses of the coal used establish a standard for plant operation and consumption, giving more uniform results and generally effecting definite savings.
4. Mine operators are compelled to mine and prepare their coal with greater care.
5. Disputes as to the quality of coal are more readily obviated or adjusted.
6. Should inferior coal be received, the buyer pays only for such quality, while if a better grade than the standard called for be received, the seller gets a higher price.
7. An exact and definite basis for cancellation of contract is provided for.
8. By insuring coal of a uniform quality, boiler room work is made easier, and more skilful handling of the coal is possible.
9. Valuable and useful information as to coals and their actual quality is acquired by both buyer and seller.
10. The seller and miner of high grade coals is enabled to secure a price commensurate with the value of his product.
11. The miner and seller of low grade coals is given a chance to compete with the better fuels.
12. The adoption of better combustion methods often

results, enabling a buyer to use, in many cases, lower grades and cheaper coals.

Disadvantages of the Purchase of Coal On Specification Basis.

1. The consumer may be made to pay more for his coal on account of increased mining and preparation costs; and the balance of price between poor and good coals will be destroyed.
2. The conservation of fuels will be defeated by the greater use of high grade coal.
3. Natural variation in coal from the same seam or mine often make it impossible for the mine operator to control or guarantee any fixed heating value.
4. It is impossible for the sampling to be always accurate.
5. By the old method of purchase coal can be sold and bought with less trouble and expense to both sides.
6. The poorer grade fuels will not be so much in demand, consequently, will remain unmined and sometimes will be lost entirely.
7. The consumer would effect greater savings in the use of coal if he would abolish wasteful methods of consumption instead of trying to save a few cents in cost of purchase.
8. Any saving in the delivered cost of coal would be more than counter-balanced by the expense required to take samples and have analyses made.
9. Competitive bidding between coals of different heating values would be restricted.
10. As sampling must be generally done by the buyer and it is not always possible for the seller to have a representative present when samples are taken, the latter is

therefore entirely at the mercy of the purchaser as regards sampling methods.

General Considerations.

The purchase of coal on specification is a condition as well as a theory; a very practical condition too, and one that demands careful consideration by both the buyer and seller. Efficiency is required in purchase as well as in use; it should apply equally to both.

"Too many buyers have looked upon the purchase of coal by specifications as a remedy for their own inefficient methods in use, to be glossed over by using only high grade fuel, which will give good results even with the most inadequate and wasteful equipment and ignorant cheap handlers. Many specifications are in use that were written from the point of view of the consumer only. They are often loosely drawn up, badly worded, unfair and apparently looking only to obtain the best article at the lowest possible price. In addition to this, they frequently leave out entirely, or dismiss in a few words, the most important item—the sampling of the coal."

Selection and Purchase.

To buy coal intelligently on any basis, the buyer must first determine the kind and size most suitable for his particular plant. This can only be accomplished by actual working tests, and should be done before any contract, whether on a specification basis or not, is made.

The most efficient plant operation, at the lowest possible cost, is the basic consideration to the plant owner. As coal is a most important item, its purchase should be given the greatest care both by the one doing the actual buying and by the one responsible for its economical use, whatever may be his position.

No buyer should decide on specifications for coal to be used at his plant until he has considered carefully the fol-

lowing items and determined upon the kind of coal that will best suit his plant and conditions.

Boilers.

1. Kind, capacity and arrangement.

Furnaces.

1. Grates, surface and setting.
2. How operated, stokers or hand-fired.
3. If stokers, kind of coal they will handle best.
4. If hand-fired, kind of grates and kind of labor available.

Draft.

1. Amount available and how controlled.
2. Kind: Natural, forced or induced.

Load.

1. Character; maximum, minimum and time.

Coal.

1. Delivery at plant, method of handling, method of storage, how much.
2. Price at mines and freight rates.
3. Capacity of mines.
4. Conditions of delivery and movement from mines to plant.
5. Kind of cars to be used.
6. Moisture and its possible effect.
7. Volatile matter; its relation to furnace condition and smoke laws.
8. Ash, its amount.
9. Fusing temperature of ash.
10. Coking qualities.
11. Skill of firing.
12. Size.
13. Heating value.

WHAT COAL SPECIFICATIONS SHOULD COVER.

The true object of the purchase of coal by this method is to ensure the buyers getting, during the life of the contract, the quality and kind of coal needed and a sufficient and uniform supply of it, at a fair price. These should be the main objects of all coal specifications.

To ensure this, there should be specified.

1. Period of time covered by contract.
2. Kind of coal, amount needed and methods of delivery; a standard analysis, as a description only.
3. The minimum and maximum of each constituent that affects the cost and efficiency of operations of the steam plant.
4. The standard price.
5. The scale of penalties or premiums to be charged up to cost of coal, which should be based directly on the losses sustained in plant operation from an inferior or the greater efficiency obtained from a better fuel.
6. The method of sampling to be used at each plant, giving also the amount of coal which each sample is to represent and the name of the person responsible for the sampling, who should be, whenever possible, the chemist who makes the analyses.
7. The method of obtaining the final price, which should specify the amount of coal that each analysis represents, as a basis for payment.

One of the most important points about sampling is the question as to who is to do it. It would seem obvious that, as the buyer and seller are both interested, the sampling should be done by an outside party. But, in the operation of most contracts calling for sampling, the work is done by a representative of the buyer, whose chemists also usually make the analyses. To overcome

this, there is generally a clause in the contract giving the seller authority to have a representative present when the samples are taken and analyses made.

UNFAIR REQUIREMENTS HAVE CREATED PREJUDICE AGAINST THE B. T. U. METHOD.

It is manifestly impossible, however, for the seller to always have a man on hand, and the practical result is that, as a rule, both the sampling and analysis are in the hands of the buyer. This is one of the reasons why many sellers object to this kind of contract, and there is no doubt that improper sampling by the buyer, whether intentional, or not, has been the source of much trouble and many disputes.

The most flagrant offenders in putting out unfair specifications have been the city and state institutions. As a general rule, they will find that their costs have been higher than they would have been under the old system, as the coal sellers generally anticipated possible losses in their bids. Simplicity in the terms of such a contract should be insisted upon as most important.

The main point to be gained for the specification contract is the general acceptance of the main principle and acknowledgment of its value and fairness. Specifications have been too elaborate and in many cases coal sellers have, bid blindly because they wanted the business merely adding a few cents per ton to cover any possible loss that might be incurred.

Under the old methods, when a fuel has been chosen by a consumer and a contract made for a supply, he has generally concluded that his interests are protected as to quality by a provision that it must come from a certain colliery or collieries and from a certain seam or seams. Were this same consumer buying copper ore, he certain-

ly would not consider this as sufficient grounds to insure that the ore would always be of the same value. Nor should such proviso be sufficient for the purchase of coal. That coal from the same seam may vary in quality is fairly well known, but that fuels from the same mine may also vary considerably is a fact not so generally recognized.

RELIABLE METHODS WILL PRODUCE ADVANTAGEOUS RESULTS FOR BUYER AND SELLER.

As to the attitude of mine operators and selling agencies, opinions today are somewhat divided. Many of the large producers are quite willing to sell on a specification basis, provided they may be assured of fair treatment. Others are against selling on any such basis and only do so when they cannot get certain large contracts in any other way. On the whole, a decided reaction has set in among coal sellers against the specification basis, and the same may be said about the large users and buyers.

As a general conclusion, it is believed by many chemists, engineers and others, that after the buyer of steam coal has decided on the description of coal he desires, and what is best adapted to his use, there are only two items to be considered, as regards analysis, in making up specifications, that is, the percentage of ash and the fusing temperature of the ash.

A standard percentage of ash of a given kind of coal (field or seam) insures a standard B. t. u. value; any change in ash percentage makes a corresponding change in B. t. u. value. The right ash-fusing temperature means no clinkers and good combustion results, if the coal is handled properly.

When smoke laws are to be observed, it may be neces-

sary to specify also a maximum volatile content of the coal, although even here it would generally be advisable and more economical in the end to alter furnace and boiler conditions, so that higher volatile, cheaper (usually) coals could be used.

Simplicity, equity and practicability, should be the characteristics of all contracts for the purchase of coal, whether on a specification basis or not.

PREPARATION OF BITUMINOUS COAL.

While the mining of coal is a matter outside of the intended scope of this Manual, the preparation of coal for the market is of such importance to the user and the salesmen, that a brief general outline of the methods employed will be given.

Coal preparation is usually understood to mean the cleaning of the coal, or the removal of extraneous impurities, such as shales (slates), bone, clay, iron pyrites, etc., together with the screening of the coal into different sizes, as required.

Cleaning of Coal.

Cleaning of the coal really begins in the mine, the miner being required (not often with success) not to load anything in the mine cars but coal.

After the coal is brought out of the mine to the tipple, as the structure where bituminous coal is cleaned, screened and loaded into railroad cars, is called, the mine cars, usually holding, in this country, from $1\frac{1}{2}$ to 3 tons, are dumped, the coal flowing into a chute or pocket and then over stationary bar or perforated shaking screens, if it is to be screened.

From the screens, or direct from the chute or pocket, if the coal is not to be screened (run-of-mine or un-screened), the larger sizes and the run-of-mine are carried

on by a wide travelling conveyor, or picking table, as it is usually called, where the different impurities are picked out by hand, the coal then going down a movable chute into the railroad car.

This is the ordinary method in use at bituminous coal mines of any size; many small mines, however, are not equipped with picking tables, and the coal is not cleaned until it reaches the railroad car, the cleaners, or slate pickers, as they are called, standing down in the car, throwing out the slate, &c. as the coal is loaded.

Washing Coal.

At many mines, however, especially when the slack or small coal is dirty and contains many small pieces of impurities, the methods just described will not suffice.

In such cases, the larger pieces of coal are screened out and cleaned by hand, while the smaller sizes are "washed," or cleaned by the action of running water with separation of the coal and impurities caused by their differing specific gravities; as the impurities are of greater specific gravity than the coal, hence the flow of water carries off the lighter coal, while the heavier impurities sink; the whole action being usually assisted by shaking or jiggling screens.

Washing reduces, in varying percentages, the amounts of both ash and sulphur in the coal, the percentage of reduction being governed by (1) the nature, size and shape of the impurities (2) by the efficiency of the washer and its operation.

Types of Washers.

There are many different types of washers varying in construction and methods of operation, but all based on the same underlying principles.

For description of the different types, the reader is

referred to E. Proschaska's recently published work, "Coal Washing."

Drying Washed Coal.

For drying the washed coal, several devices are in use today.

Dewatering pits or bins, elevators or conveyors.

Centrifugal dryers, such as the Elmore dryer.

For handling the sludge (the fine material, under 1/16", a mixture of water and solids) classifiers and filters are used.

The extent to which drying must proceed, depends upon the percentage of moisture allowable in the washed coal, as determined by the purpose for which the coal is to be used.

If for making coke, 12 per cent is about the maximum moisture allowed, but probably 6 to 8 per cent is about the average required for the best results.

If the coal is to be used as fuel in furnaces, moisture should not exceed 10 per cent.

"Dry" Washing.

There are also several "dry washing" methods in use, where the same difference in specific gravity is made use of, without the action of water. Recently two new methods have been discovered, which look most promising, one an adaptation of the froth flotation process, extensively used for minerals separation—the other a process originally applied to the cleaning and separation of ores, seeds, nuts and grains, in which a slight air pressure takes the places of water, specific gravity being made use of in both methods. In the latter process, invented in this country and now being installed at several large collieries, air is used as the flotation medium, its pressure being just sufficient to cause a stratification of the

material, the mass of particles becoming practically a fluid; the heavier particles (impurities) settling through the mixture and being carried off at different points along a corrugated, oscillating, concentrating deck or table.

This method undoubtedly has great possibilities; both installation and operating costs are low and tests of various coals have shown some remarkable results. (See "Coal Age", 1921, June 7 and 14 issues.

CHAPTER IV.

SAMPLING AND ANALYSIS OF COAL.

Samples of coal and coke are usually taken for the purpose of making analyses, either

1. To determine the nature and character of the coal, its suitability for different uses and for comparison with other coals, or for research purposes.
2. To determine the quality of coal, in its various characteristics, heating value, &c., where the purchase of the coal is based on its quality and payment made on such a basis, or in other words, when the coal is bought on specifications.

Whatever may be the purpose of taking samples, the utmost care should be used and samples taken according to recognized standard methods, as the value of the analysis results depend entirely upon the sample being properly taken so as to represent, as nearly as possible, the coal sampled.

Many published analyses and a great number of those used in the trade are practically valueless, because the samples from which they were made were not taken properly; analyses of picked or selected samples are used entirely too often, misleading both the buyer or user and often, unconsciously, the seller also.

The common use of analyses of picked samples on letter-heads and by selling companies is not good practice, especially when the user knows that they do not correctly represent the average quality of his coal either in the seam or as mined and shipped. In many cases, however, the producer or seller is ignorant of the true value of his coal and believes that any analysis is correct, as long as it was really made of his coal, no matter how the sample was taken.

The most common faults in sampling are:

- 1st. Not taking a sufficiently large sample.
- 2nd. Not taking the sample in such a way as to truly represent the coal samples.
- 3rd. Not using sufficient care or proper methods in reducing the original or "gross" sample, as it is called, to the amount required for the chemists use.

As to the size of sample to be taken, it is difficult to give any hard and fast rule; this depending upon the size and amount of impurities in the coal to be sampled.

Proper sampling needs intelligence, care and some training. If a sample is to be taken, it should be taken in the right way; leaving it to an inexperienced boy or an ordinary laborer or to one who knows nothing about proper methods is not the right way. Yet important sampling, involving thousands of dollars, is often handled by ignorant or careless labor.

If coal is to be paid for on the basis of its analysis, a standard method of sampling should be contained in the purchase contract; the method of handling at the laboratory should also be specified.

The American Society for Testing Materials, adopted, in 1916, a standard method for sampling coal, as a re-

sult of several years of investigation; the same method is used by the U. S. Bureau of Mines.

The official description is given herewith in full. For further information the reader is referred to the 1918 report of the American Society for Testing Materials, "Standards for 1918."

1. FOR ALL DETERMINATIONS EXCEPT TOTAL MOISTURE

Time of Sampling. 1. The coal shall be sampled when it is being loaded into or unloaded from railroad cars, ships, barges or wagons, or when discharged from supply bins, or from industrial railway cars, or grab buckets, or from any coal-conveying equipment, as the case may be. If the coal is crushed as received, samples usually can be taken advantageously after the coal has passed through the crusher. Samples collected from the surface of coal in piles or bins, or in cars, ships or barges are generally unreliable.

Size of Increments. 2. To collect samples, a shovel or specially designed tool, or mechanical means shall be used for taking equal portions of increments. For slack or small sizes of anthracite, increments as small as 5 to 10 lb. may be taken, but for run-of-mine or lump coal, increments should be at least 10 to 30 lb.

Collection of Gross Sample. 3. The increments shall be regularly and systematically collected, so that the entire quantity of coal sampled will be represented proportionately in the gross sample, and with such frequency that a gross sample of the required amount shall be collected. The standard gross sample shall not be less than 1000 lb., except that for slack coal and small sizes of anthracite in which the

impurities do not exist in abnormal quantities or in pieces larger than $\frac{3}{4}$ in., a gross sample of approximately 500 lb. shall be considered sufficient. If the coal contains an unusual amount of impurities, such as slate, and if the pieces of such impurities are very large, a gross sample of 1500 lb. or more shall be collected. The gross sample should contain the same proportion of lump coal, fine coal, and impurities as is contained in the coal sampled. When coal is extremely lumpy, it is best to break a proportional amount of the lumps before taking the various increments of a sample. Provision should be made for the preservation of the integrity of the sample.

Quantity Represented. 4. A gross sample shall be taken for each 500 tons or less, or in case of larger tonnages, for such quantities as may be agreed upon.

TABLE 1.

Weight of Sample to be Divided, lb.	Largest Size of Coal and Impurities Allowable in Sample Before Division, in.
1000 or over -----	1
5000 -----	$\frac{3}{4}$
250 -----	$\frac{1}{2}$
125 -----	$\frac{3}{8}$
60 -----	$\frac{1}{4}$
30 -----	3/16 or 4-mesh screen

Crushing 5. After the gross sample has been collected, it shall be systematically crushed, mixed, and reduced in quantity to convenient

size for transmittal to the laboratory. The sample may be crushed by hand or by any mechanical means, but under such conditions as shall prevent loss or the accidental admixture of foreign matter. Samples of the quantities indicated in Table 1 shall be crushed so that no pieces of coal and impurities will be greater in any dimension, as judged by eye, than specified for the sample before division into two approximately equal parts.

The method of reducing by hand the quantity of coal in a gross sample shall be carried out as prescribed in Section 6, even should the initial size of coal and impurities be less than indicated in Table 1.

Hand Preparation	6. The progressive reduction in the quantities indicated in Table 1 shall be done by the following methods.
Mixing and Reduction by Discarding	(a) The alternate-shovel method of reducing the gross samples shall be repeated until the sample is reduced to approximately 250 lb., and care shall be observed before each reduction in quantity that the sample has been crushed to the fineness prescribed in Table 1.
Alternate Shovelful	

The crushed coal shall be shoveled into a conical pile by depositing each shovel of coal on top of the preceding one, and then formed into a long pile in the following manner: The sampler shall take a shovel of coal from the conical pile and spread it out in a straight line having a width equal to the width of the shovel and a length of 5 to 10 ft. His next shovelful shall be spread directly over the top of the first shovelful, but in the opposite direction, and so on back and forth, the pile being occasionally flattened, until all the coal has been formed

into one long pile. The sampler shall then discard half of this pile, proceeding as follows:

Beginning on one side of the pile, at either end, and shoveling from the bottom of the pile, the sampler shall take one shovelful and set it aside; advancing along the side of the pile a distance equal to the width of the shovel, he shall take a second shovelful (shovelful No. 2) and discard it; again advancing in the same direction one shovelful width, he shall take a third shovelful (shovelful No. 3) and add it to the first. The fourth (shovelful No. 4) shall be taken in a like manner and discarded, the fifth (shovelful No. 5) retained, and so on, the sampler advancing always in the same direction around the pile so that its size will be gradually reduced in a uniform manner. When the pile is removed, about half of the original quantity of coal should be contained in the new pile formed by the alternate shovelfuls which have been retained.

Mixing and Reduction by Quartering After the gross sample has been reduced by the above method to approximately 250 lb., further reduction in quantity shall be by the quartering method. Before each quartering, the sample shall be crushed to the fineness prescribed in Table 1.

Quantities of 125 to 250 lb. shall be thoroughly mixed by coning and re-coning; quantities less than 125 lb. shall be placed on a suitable cloth, measuring about 6 by 8 ft., mixed by raising first one end of the cloth and then the other so as to roll the coal back and forth, and after being thoroughly mixed shall be formed into a conical pile by gathering together the four corners of the cloth. The quartering of the conical pile shall be done as follows:

The cone shall be flattened, its apex being pressed vertically down with a shovel, or board, so that after the pile has been quartered, each quarter will contain the material originally in it. The flattened mass, which shall be of uniform thickness and diameter, shall then be marked into quarters by two lines that intersect at right angles directly under a point corresponding to the apex of the original cone. The diagonally opposite quarters shall then be shoveled away and discarded and the space that they occupied brushed clean. The coal remaining shall be successively crushed, mixed, coned and quartered until the sample is reduced to the desired quantity.

(c) The 30 lb. quantity shall be crushed to 3/16 in. or 4-mesh size, mixed, coned flattened and quartered. The laboratory samples shall include all of one of the quarters, or all of two opposite quarters, as may be required. The laboratory sample shall be immediately placed in a suitable container and sealed in such a manner as to preclude tampering.

Mechanical Preparation 7. Only such mechanical means as will give equally representative samples shall be used in substitution for the hand method of preparation herein standardized.

II. FOR THE DETERMINATION OF TOTAL MOISTURE

Collection of Moisture Sample 8. The special moisture sample shall weigh approximately 100 lb., and shall be accumulated by placing in a waterproof receptacle with a tight-fitting and waterproof lid small equal parts of freshly taken increments of the standard gross sample. The accumulated moisture sample shall be rapidly crushed and reduced mechanically

or by hand to about a 5-lb. quantity, which shall be immediately placed in a container sealed air-tight and forwarded to the laboratory without delay.

Use of Standard Gross Sample 9. Only when equally representative results will be obtained shall the standard gross sample be used instead of the special moisture sample for the determination of total moisture.

"It is imperative that every sample be collected and prepared carefully and conscientiously and in strict accordance with the standard methods described herein, for if the sampling is improperly done, the sample will be in error, and it may be impossible or impracticable to take another sample; but if the analysis is in error, another analysis can easily be made of the original sample.

Gross samples of the quantities designated herein must be taken whether the coal to be sampled consists of a few tons or several hundred tons, because of the following cardinal principle in sampling coal that must be recognized and understood; that is, the effect of the chance inclusion or exclusion of too many or too few pieces of slate or other impurities in what, or from what, would otherwise have been a representative sample will cause the analysis to be in error accordingly, regardless of the tonnage sampled. For example, the chance inclusion or exclusion of 10 lb. too much or too little of impurities in or from the otherwise representative sample of 100 lb. would cause the analysis to show an error in ash content and in heat units of approximately 10 per cent, whereas for a 1000 lb. sample, the effect would be approximately only 1 per cent, being the same whether the sample is

collected from a 1-ton lot or from a lot consisting of several hundred tons.

When this method of sampling is to be employed as a part of any contract or agreement, the following provisions shall be specifically agreed to by the parties of such contract or agreement.

- (a) The place at which the coal is to be sampled (see Section 1.)
- (b) The approximate size of the sample required when the standard conditions do not apply (see Section 3.)
- (c) The number of samples to be taken or the amount of coal to be represented by each sample when the standard conditions do not apply (see Section 4.)"

U. S. Bureau of Mines Sampling Methods.

Bulletin 116, issued by the Bureau in 1916, gives complete and minute instructions regarding coal sampling, together with much useful data in connection with the subject.

Theory of Sampling.

"To determine with utmost accuracy the ash content and heating value of a quantity of delivered coal would require the burning of the entire quantity, and special apparatus arranged to measure the total heat liberated, or would require crushing the whole quantity, and reducing it by an elaborate scheme of successive crushings, mixings, and fractional selections to portions weighing approximately 1 gram, the minute quantity which the chemist requires for each determination. Either of these procedures is obviously impracticable if the coal is to be used for the production of heat and power.

The method actually employed is to select portions

from all parts of a consignment or delivery of coal and to systematically reduce the gross sample, obtained by mixing these portions, to quantities that the chemist requires for making ash determinations or that can be burned conveniently in the calorimeter, an apparatus for determining the heating value. The gross sample should be so large that the chance admixture of pieces of slate, bone coal, pyrite, or other impurities in an otherwise representative sample will affect but slightly the final results. Increasing the size of the gross sample tends toward accuracy, but the possible increase is limited by the cost of collection and reduction. In reducing the gross sample by successive crushings and halvings or fractional selections, the object is to procure a small laboratory sample that, upon analysis, will give approximately the same results as the gross sample itself, or, in fact, the entire quantity of coal from which the gross sample was obtained."

Sampling Coal In the Mine.

In order to secure a sufficient number of samples to fairly represent the entire area of active and future workings, a general inspection of the mine should be made, and, with the aid of the mine map, places for taking the samples should be selected, the number depending of course, upon the size of the mine and the number of working places. About eight places for every 500 tons per day output is considered to be a sufficient number ordinarily.

Method of Sampling In Mines.

The standard method used by the U. S. Geological Survey and Bureau of Mines is as follows:

"Having selected the representative faces of the bed to be sampled, the collector clears the surface of burned

powder, dirt, or loose coal from roof to floor with a width of about 5 feet. Insecure pieces of the roof are also taken down. This is done to prevent any loose fragments or foreign matter from falling off the face of the coal onto the sampling cloth. In the middle of this cleared area on the face, the coal is cut away with the pick from the roof to the floor for a width of 1 foot and a depth of at least 1 inch, with a view to removing any discolored, altered, or otherwise inferior coal that might be near the surface, and also to square up this part of the face in preparation of the sampling cut. The floor is then cleaned and smoothed, and a stout waterproof sampling cloth measuring 6 by 7 feet is spread with one edge next to the coal.

A gross sample weighing at least 6 pounds for each foot of thickness of the bed is then obtained by making a perpendicular cut 2 inches deep and 6 inches wide (or 3 inches deep and 4 inches wide in the softer coals) from the roof to the floor down the middle of the foot-wide cut previously made in the coal face. The impurities of bone, "slate", shale, pyrite, etc., are included or rejected according as these impurities are included or rejected in the ordinary operation of the mine. Usually partings more than three-eights of an inch thick, and lenses or concretions of "sulphur" or other impurities more than 2 inches in maximum diameter and one-half inch thick are excluded, if in the judgment of the sampler they are being excluded by the miner from the coal as loaded out of the mine or as shipped.

As soon as the cutting of the sample has been completed, it is crushed until all the material passes through a one-half inch screen. Any impurities, such as "slate" (shale) or pyrite, are crushed to a one-fourth inch diameter or finer. The gross sample is then thoroughly

mixed by two men grasping the opposite corners of the sampling cloth and rolling the cloth diagonally by raising one corner at a time. The pile is then flattened at the top and quartered, the two opposite quarters being discarded and brushed off the sampling cloth. The remainder is mixed as before, and if the sample is still too bulky for convenient handling it is again quartered. The material finally remaining is spread into a circular mass about 2 inches deep on the sheet, and a galvanized-iron sample can of about 3 pounds capacity is filled compactly with parts taken from various parts of the mass.

As soon as the can has been filled and a description label placed inside, the cap is screwed on so that the top of the screw fits tightly into the rubber or other flexible material in the cap; adhesive tape is then carefully wrapped around the lower edge of the cap in such a manner as to cover the joint and increase the thoroughness of the sealing.

The entire operation described above, from the cutting of the sample to the sealing of the can, is done in the mine, so that the coal may not be exposed to the outside atmosphere and thus lose moisture.

ANALYSES

Analyses of coal and coke are made to determine, as far as possible, the character of such fuels and their suitability and value for various uses.

For such purposes, analyses have been in use for at least 40 years, but their extended practical use in this country, dates back to about 1890, since when their value has become more and more recognized, with increasing use and greater accuracy in their results, as the methods of analyses have been improved.

Unfortunately, standard methods of analyses have not always been used in all determinations, so that it is necessary to know something about how an analysis has been made, before we can accept it as accurate and trustworthy; more important still, we must have knowledge of how and where the sample analyzed was taken; many analyses are valueless for any practical purpose, because the samples from which they were made were not representative.

We must note also that the exact value of coal and its suitability for various uses cannot be always determined from analyses, although they give us valuable and necessary information. Other special tests are quite often necessary; analyses give little information or indication as to whether a coal will coker or not nor do they show whether a coal will make a good coke or not.

As applied to coal and coke, there are two kinds of analyses in use.

1. Proximate.
2. Ultimate.

Proximate Analysis.

This may be described as the determination of the amounts of certain general constituents, for the purpose of showing the general character of the coal analyzed, the amounts being usually given in terms of percentage by weight.

This form of analysis gives results of the determination of—

1. Moisture.
2. Volatile Matter.
3. Fixed Carbon.
4. Ash.

5. Sulphur, always separately determined and not, strictly speaking, a part of the proximate analysis, although usually given with it.

The heating value of the coal is often given along with the proximate analysis, but this value is not part of the analysis and is determined separately, by actual combustion, as described elsewhere.

Ultimate Analysis.

The ultimate analysis, much more difficult to make and of course, more expensive, separates the general constituents of the coal, as determined by the proximate analysis, into their elements, as shown by the following tables:

Ultimate Into Proximate.

1. Carbon— (Fixed Carbon of Proximate Analysis.
(Volatile Carbon in Volatile Matter of Proximate Analysis.)
2. Hydrogen— (Hydrogen in Moisture.
(Hydrogen in Volatile Matter.)
3. Oxygen— (Oxygen in Moisture.
(Oxygen in Volatile Matter.)
4. Nitrogen— (Volatile Matter.
(Fixed Carbon.)
5. Sulphur— (Sulphur Volatile.
Fixed.)
6. Ash— (Same as in proximate analysis.)

Proximate Into Ultimate.

1. Moisture— (H
(O)
3. Fixed Carbon (C
(N
(S

2. Volatile—	(H	(N	
	(O	(S	4. Ash.
	(C		

CONSTITUENTS DETERMINED BY PROXIMATE ANALYSES.

Moisture.

Moisture in coal exists in two ways:

(1) Extraneous or "accidental" moisture, from outside sources; rain, water percolating through the seam from the adjoining rocks, precipitated on coal when exposed to air, "sweating."

(2) Inherent moisture, from the original organic matter of the coal or caused by chemical changes in the coal.

Extraneous or superficial moisture may vary from less than one to 30 or 40 per cent, depending upon the character of the coal, the seam conditions and exposure of the coal to the weather, as well as upon the size of the coal; slack or screenings will hold more water than will lump.

All water in coal above about 3 per cent in the Appalachian coals, 12 per cent in the Middle Western and 22 per cent in the sub-bituminous coals may be classed as superficial.

Inherent or vein, hygroscopic moisture may vary from less than one per cent to 20 or 30 per cent in lignites.

In the combustion of coal, small amounts of moisture such as are contained by high grade coals, have so little effect that they can be disregarded under ordinary conditions; a loss of 0.1 per cent of the total heating value of the coal for each per cent of moisture will be the extent of the loss.

Large amounts of moisture, however, such as are con-

tained by low grade coals and lignites may cause appreciable losses, not only in actual combustion, but in the breaking up of the coal when exposed to heat or weathering.

Coals with high moisture content are also more liable to spontaneous combustion.

There is also a loss from moisture due to the fact that its weight must be included in freight charges on the coal and paid for as coal.

It is a common practice in boiler rooms and a universal one on locomotives to wet the coal before it is fired. This custom is partly due, especially on locomotives, to keep coal dust from flying around, but there is also another reason given—that it "makes the coal burn better." In a circular of instructions to Enginemen and Firemen, issued by the Motive power department of the Pennsylvania Railroad in 1908, one rule reads: "The sprinkling hose must be used frequently to keep down dust on the footplate and in the cab and to **wet coal in the tender**. However, too much water on the coal should be avoided, as to some extent this practice is the cause of flues stopping up."

With some bituminous coals there is a mechanical action brought about by wetting (not soaking) the coal which has a beneficial action in the furnace. No conclusive tests have ever been made, as far as the writer knows, to determine just what this action is and its effects, but the probable action is the packing of the coal, where it is placed on the fire and a possible retardation of gas distillation. (See Locomotive Fuels.)

Volatile Matter.

The volatile matter of coal, as determined by proximate analysis, is made up of the gases and liquids distilled

from the coal when it is heated to certain temperatures.

It consists of both combustible and incombustible gases, the former hydrogen and carbon, the latter, oxygen and nitrogen; care should be taken to distinguish between the terms "volatile" or "volatile matter" and "volatile combustible", as sometimes given in reports of analyses.

The determination of volatile matter in coal is not absolute, and the amount of volatile, as reported, may vary considerably, according to the method of determination used.

Several things affect the amount of volatile matter as determined; the kind of apparatus, the length of time the sample is heated, the temperature, the size of flame used, difference in the burner, the fineness and dryness of the sample, all may affect the result obtained.

For this reason, comparison of volatile matter in coals are sometimes misleading; for the same reason quite different percentages of volatile are often given for samples of coal from the same mine, as reported by different laboratories; two laboratories are likely to vary **2 per cent** in volatile matter determinations, both using the same method.

For instance, in 1909, a large number of samples were taken by the U. S. Geological Survey inspectors from certain mines in the low-volatile coal fields of West Virginia and Pennsylvania.

The analyses of these samples as reported in Bulletin 22, U. S. Bureau of Mines, showed the volatile matter as being much lower than had ever been reported by other laboratories on the same coals, and lower than was afterwards reported on coals from the same districts and coal seams, by the Bureau.

The difference was found to be due to the different conditions of determination, as was afterwards explained

by the Bureau of Mines, natural gas having been used in one case and artificial gas in the other.

To obviate such differences in results, the American Chemical Society and the American Society for Testing Materials, have adopted a standard method which is now generally used in this country; no determination of volatile matter should be accepted for use or comparison unless made according to this method.

By its use, different determinations should not vary over one per cent, in results.

Character of Volatile Matter.

While the percentage of volatile matter in two or more coals may be practically the same, the character of the volatile in each may be entirely different and the percentage of the different constituents that make up the volatile may vary considerably.

Varying amounts of moisture, oxygen and hydrocarbons may and often do greatly alter the characteristics of coals otherwise similar.

The heating value of the volatile matter depends upon the percentage of **available** hydrogen and carbon which it contains.

Volatile Matter In Combustion, Importance of.

The importance of volatile matter in all industrial uses of fuel is recognized by everyone.

If coal is used for steam making, the quantity and quality of the volatile and its ease of liberation on combustion have much to do with boiler efficiency, as well as with the production of smoke.

There are more heat units in the volatile matter, in proportion to its weight, than in the fixed residue of the coal. For instance, a Pittsburgh seam coal with 30 per cent volatile matter and seven per cent ash, has

36 per cent of its heating value in the volatile matter. But equal **weights of volatile** combustible matter develop comparatively less heat as the quantity of the volatile substances increases, while equal weights of carbon, no matter from the coal they were derived, always yield the same amount of heat units.

Fixed Carbon.

Fixed carbon is the residue left after the volatile matter and ash have been deducted, hence it is not an actual determination, but is determined by calculation; 100 minus the sum of the percentages of ash, moisture and volatile matter equals the fixed carbon percentage. Fixed carbon of the proximate analysis always differs from the total carbon as shown by the ultimate analysis, as a portion of the latter is given off with the volatile matter.

Fixed carbon is **not** pure carbon and any statements regarding heating value of a coal based on its fixed carbon percentage, are apt to be misleading.

Ash.

Ash in coal is that portion of the mineral substances in the coal which remains behind after the combustible has been burned; it is the inorganic substance in coal, together with water.

It consists of the ash content of the vegetable matter from which the coal was burned, plus the mineral and rocky matter mixed with the coal, and that derived from the strata above and below the coal seams.

Ash is inert; not only does it not produce heat, but it actually absorbs heat units in reaching the temperature of the fire, and is a complete loss as far as fuel value is concerned.

It must be removed, in a more or less heated state,

from the grates, its removal carrying off heat, together with a certain amount of unconsumed fuel, such amount depending upon the character of the coal, the furnace equipment and its condition and the skill of the fireman.

Chemically, it is a very complex substance and its composition varies greatly; it contains in varying proportions—silica, alumina, iron, lime, magnesia, arsenic, sodium, titanium, potassium, etc.

To show the variation in amount of its constituents, the following analyses of ash are given. (U. S. Bureau of Mines, Bulletin No. 129).

COAL	Low		Low		High		High	
	Volatile	W. Va.	Volatile	Penna.	Volatile	W. Va.	Volatile	Penna.
Ash -----	7.4	5.7	7.0	7.4	10.9		12.3	
Silicia -----	54.3	59.7	43.8	30.3	50.4		56.8	
Alumina -----	24.6	26.4	29.0	24.6	24.0		28.2	
Iron Oxide ---	12.4	7.0	18.4	37.9	20.4		11.3	
Lime -----	1.4	2.6	2.6	3.0	1.7		1.0	
Magnesia -----	0.4	1.3	.2	0.2	0.2		0.8	
Sodium -----	2.8	---	.5	0.5	1.0		0.6	
Titanium -----	1.1	---	2.6	1.3	1.4		1.2	
Potassium ---	1.9	---	1.1	0.6	1.0		1.6	
Sulphur, total-	0.9	0.6	1.4	2.7	2.7		1.8	
in coal.								

Ash, Extraneous.

A distinction must be made between the ash inherent or fixed in the coal and the extraneous ash which can be removed by hand picking, mechanical cleaning or washing.

The latter generally consists of particles of shale, clay, sandstone and pyrites; it comes from, either partings in the coal bed or from the shales or sandstones above (top) or below (bottom) the coal bed, or, in the case what is called "bone" or "bony coal" niggerhead, cannel slate, etc., of small particles of impurities intimately associated with coal, the whole forming really, a high ash coal.

The amount of extraneous ash in commercial coal is often much greater than the amount of inherent ash.

To illustrate—a selected sample of carefully mixed and quartered West Virginia coal was analyzed and found to contain 4 per cent of ash. A portion of this final sample was then carefully cleaned, using a high power magnifying glass, the analysis of this portion showing 1.10 per cent ash.

Ash In Small Sizes.

As a general rule, the amount of extraneous ash is greater in the smaller sizes of coal. For instance, a good anthracite, egg size, will average about 7 per cent ash, while No. 3 Buckwheat will run from 18 to 25 per cent.

There are some coals, however, to which this rule will not apply, usually when the extraneous impurity is very hard and difficult to separate from the coal itself, or where the harder coal in the bed contains more innate ash than the softer portions.

With some of the high-grade semi-bituminous coals, such as Pocahontas, if we take a sample and throw out all slate, bone, etc., and separate the harder pieces of coal from the softer and more friable, it will be found that the softer coal will contain a lower percentage of ash, hence the slack or smallest size will often contain less ash than the larger sizes, depending upon how well the coal has been cleaned and the outside impurities removed.

Ash, Character of.

Now, while the amount of ash in coal is an important factor, the character of ash is a still more important one, in the actual burning of the coal for most purposes.

A coal having high heating value and consequent small amount of ash, as determined by analysis, may so act in actual burning in the furnace that it is impossible to get

the results that should be obtained, based on its high heating value.

To determine the amount of ash in a coal is, therefore, not sufficient, if we are considering its value as a fuel, especially for steam making and in gas producers and industrial furnaces; we must also know the character of the ash, whether it will clinker much or little and what kind of clinker it will give.

Determination of Clinkering Tendency of Ash.

There are but two ways to determine the character of ash as regards clinkering tendency.

1st.—To burn the coal in the furnace under actual working conditions.

2nd.—To determine the fusing point or temperature at which the ash will fuse or soften.

The first method we will not discuss at any length; it is as old as the use of coal.

But, we should remember, that, before it can be determined whether a coal will clinker badly or not, the conditions under which it is to be burned must be known. In other words, a coal that will clinker badly at one plant, may not do so at another, where the conditions of its use may be entirely different.

The human equation is also a factor—firemen are different and of varying degrees of skill. The skill of a good fireman is never shown to greater advantage than in his methods of minimizing clinkering, in cleaning fires and keeping them clean; this applies to stoker firing as well as to hand firing.

2nd. This method of determining the character of coal ash, with especial reference to its clinkering qualities, is of comparatively recent date, as far as its practical use is concerned.

Ash Analysis As Determining Clinkering.

It is claimed by some authorities that the clinkering activity of a coal can be accurately determined from analysis of the ash. This is probably true in a measure and for some coals, but its universal application is of doubtful value.

Even if it is possible to ascertain from its ash analysis whether a coal will clinker badly or not, it is certainly more accurate and easier, as well as cheaper today, to have the ash fusing temperature determined.

Professor Bone says:

"The relation of the fusibility of the ash of a coal to its chemical composition is a very important though somewhat complex question, concerning which the present state of our knowledge is not sufficiently definite to warrant the laying down of any precise rules."

Professor Brame states:

"Whilst it is impossible to correlate composition of the ash with clinkering property, it is certain that the nearer the composition approaches that of aluminum, silicate ($AL_2 O_3$, $2SiO_2$; $AL_2 O_2$ —45.8 per cent, SiO_2 —54.2 per cent.) the more infusible it (the ash) will be."

Ash Fusing Temperature or Softening

Point of Ash and Its Determination—

What It Means.

The softening or fusing temperature of ash is that point at which the ash, when molded into a solid triangular pyramid $\frac{3}{8}$ inch high and $\frac{1}{4}$ inch wide at the base, standing vertically, has fused or melted down to a round lump. The temperatures at which the tip of the ash cone first softens and at which the ash has become fluid are also important as showing how much the melting ash will "run" or, its viscosity.

Considerable variations are found in ash-fusing temperatures, from 1900° to 3100° Fahrenheit; such variation is conclusively proved by actual combustion in the furnace.

Fusing Points Standard of Division.

The following division of fusing points has been adopted, by the U. S. Bureau of Mines, for convenience of statement.

Class 1. Refractory ash, softening above 2600°F.

Class 2. Ash of medium fusibility—maximum 2600°F.
—minimum 2200°F.

Class 3. Easily fusible ash, softening below 2200°F.

In actual use, it may be safely stated that any coal with a determined ash-fusing point of over 2600°F. should give no trouble from clinkers, provided the sample on which the ash-fusing determination was made fairly represented the coal used, and the determination was made according to approved methods.

Ash-Fusing Temperatures, Variations In.

Ash-fusing points may vary considerably, even in coal from the same mine.

In the Bureau of Mines test results of ash-fusing temperature determinations, we find ample corroboration of this statement. In the case of one large mine in West Virginia, four samples tested varied from 2160 to 3010°F.

In another large well-known Pennsylvania mine, coal from which is used by the Navy, we find in ten samples tested variation of 750°, 2260° to 3010°F.

To illustrate some of the effect of clinkering or the results obtained in actual practice between two coals of the same character (both low-volatile with practically the same heating value and ash content, but with a marked difference in ash-fusing temperatures, the follow-

ing boiler operation data are given, the same boiler and fireman being used on both tests. (E. G. Bailey, 1911.)

Analysis of Coal	A	B
Moisture, per cent -----	2.75	4.11
Volatile, per cent -----	16.96	21.82
Fixed Carbon, per cent -----	74.50	68.38
Ash, per cent -----	5.80	5.69
Sulphur, per cent -----	0.71	1.27
Dry basis ash, per cent -----	5.96	5.93
Dry basis B. t. u. -----	14802	14806
Fusing temperatures of Ash °F.-----	2750	2390
Boiler Test , duration of test, hrs. ---	24	24
Weight of coal burned, lbs. -----	24,974	24,603
Total weight of ash refuse -----	1,905	746
Percentage of clinkers to Ash in coal burned -----	20.2	53.3
Calculated total grate area obstructed by clinker sq. ft. -----	22	79
Average steam pressure lbs. -----	102.0	97.2
Percentage of rated H. P. developed -----	90.2	86.5
No. times fires cleaned -----	2	5

Variation In Clinkering.

Actual experience in handling and burning coals will confirm this possible variation in clinkering characteristics and tendencies. Some of the worst clinkers seen in the writer's experience came on several occasions from coal produced from a large mine, the coal from which usually gave no trouble from clinkers at all; fusion point determinations of three different samples taken from different lots of coal from that mine showed a variation of 610°F. On the other hand, some coal beds and many

mines show consistent uniformity in ash-fusing temperatures, some uniformly high and some the reverse.

Samples from adjoining mines in the same bed will sometimes give widely varying results in the product of each mine as for example, six samples from Mine A showed a range of from 2100 to 2520°F., while 8 samples from the adjoining mine B in the same bed, varied only from 2850 to 3010°F.

It would seem, therefore, that we must not rely too much on ash-fusing temperature determinations alone, in determining the clinkering characteristics of coal from any mine or group of mines. The buyer or user can, however, always obtain or require a **standard** ash-fusing temperature, which will be of assistance to him in purchase.

Ash Fusing Temperature Determinations, Earliest Use of.

The first laboratory in this country to undertake the determination of fusing point of ash, as a commercial proposition, was that of the Fuel Testing Co. of Boston under the direction of Mr. E. G. Bailey, to whom, with Mr W. B. Calkins, is due, we believe, the credit for the first active work in bringing the question to the notice of coal producers and users, in 1910.

Later on, the question was taken up actively by the U. S. Bureau of Mines, who have issued two bulletins on the subject and whose investigations are still going on.

Professor L. S. Marks, also made a series of investigations on the fusibility of coal ash and the formation of clinkers, results of which were published in "Engineering News", in 1910.

Since then, the determination of ash fusibility has been

widely taken up, both in this country and abroad, so that all well-equipped coal testing laboratories are now able to make such determinations.

Clinkers. "A Mass of Fused or Molten Ash."

An accumulation of clinkers in a boiler furnace is one of the most annoying things in power-plant, gas producer or locomotive operation and is the cause of many shutdowns and much loss of time. It either cuts off the air supply almost entirely or else causes an unequal distribution of air to the fire; it takes up valuable room in the furnace, will cause the loss of considerable heat and partly burned coal, sticks to the wall of the furnace, destroying the brick eventually, and cutting off grate surface, and is altogether a nuisance to the firemen and a cause of more or less serious loss to the owner of the plant. Clinkers in the locomotive firebox are not so detrimental as in the stationary boiler plant, as the former is always equipped with shaking grates and the draft is always stronger, so that more air is "pulled" through the fire—but in marine work they are the source of great trouble and loss owing to the limited space and heat in the stokehold and to the fact that fires must be cleared while the screw is making the required number of revolutions, without any loss in steam pressure; and only a comparatively few ships' boilers have shaking grates.

Clinkers may, in a general way, be said to be due to the temperature of the fuel bed reaching the temperature at which the ash will fuse, so that the formation of clinkers depends upon two main items; the fusing point of the ash and the temperature to which the ash is exposed. The presence of certain substances in the ash, such as iron oxides, lime magnesia and alkalis will, according to their amount, lower the fusing point of the ash, while high

rates of combustion and frequent stirring and slicing of fires will increase the temperature to which the ash is exposed.

It must be understood that these substances and the other oxides are not fusible themselves, but unite to form compounds that are fusible. Lime, for instance, will not of itself fuse under any temperature, but combined with silica and alumina may cause the formation of a readily fusible slag at quite ordinary furnace temperatures.

It should be stated, in this connection, that the more silica or the more alumina contained, the more lime is required to make a fusible ash. Dr. Fulweiler gives the following advise, applying to the constituents of ash, as shown by analysis.

Avoid using an ash containing:

Silica below 30 per cent.

Alumnia below 30 per cent.

Iron Oxide above 15 per cent.

Lime above 10 per cent.

Magnesia above 3 per cent.

The distribution of the mineral constituents in the coal also has considerable effect on the clinker formation. Where much of the coal is in small particles, the ash will usually, being heavier than the coal, work down to the lower part of the fuel where the heat is not so great and hence will not clinker as readily. Fineness of subdivision of the ash is also a factor.

Clinkers, Appearance of.

There is a great difference in the appearance of clinkers. Some are a light gray color, thick, but light, porous and friable. Some are of a reddish brown thick, hard and heavy, some of dark brown tipped with jet black, thin, and heavy—while the writer has seen clinkers formed

from the coal of the Cauca Valley in Colombia, S. A. that were of a bright yellow on the outside and jet black inside.

The thick, heavy clinkers and the porous ones do not as a rule adhere to the grate and can be readily pulled out, while the thin clinkers often run all over the grates if the fires are forced and are about the consistency of molten iron, so that when the slice bar is run down the fire the pasty mass will adhere to the bar and follow it out of the fire like molasses when a stick is drawn out of it. From some coals will be formed in a very few hours a clinker the size of which will be limited only by the size of the grates, while from other coals the clinker will be insignificant in size and weight and of little detriment to combustion. With some of the New River-Pocahontas coals of West Virginia the writer has seen fires run for 84 hours without cleaning, under boilers running above their rated capacity and on locomotives runs of over 200 miles, without shaking the grates and with the fire in better condition at the end of the run than at the start.

Some coals will, at the end of three or four hours, make such troublesome clinkers that the fires must be thoroughly cleaned in order to keep up steam. It should be said, in this connection, that clinkering coals may be burned with much less trouble in locomotives than under stationary or marine boilers; the temperature in stationary boiler furnaces is higher than in locomotive fire-boxes and the fires are usually sliced and disturbed more frequently, while in marine work there is usually a continued levelling and slicing of fires.

In the Pennsylvania Railroad Locomotive tests at St. Louis, using a selected low volatile Pennsylvania coal, the firebox temperature ran from 1400 to 2000 degrees F.

when working light and from 2100 to 2300 degrees working hard, the maximum having been 2339 degrees. In the U. S. Geological Survey tests at St. Louis under stationary boilers, (Bulletin 290 and 322), taking the Pennsylvania, Virginia and West Virginia coals, the average furnace temperature of 62 tests was 2444 degrees, the lowest 2220 and the highest 2864 degrees.

Pennsylvania coals average of 21 tests... 2362°F.
West Virginia coals average of 29 tests... 2481°F.
Virginal coals average of 12 tests----- 2500°F.

While not exactly pertaining to the subject, it is interesting to note the difference between the furnace temperature, on these same tests, of the high carbon coal and the high volatile coals. They show as follows:

53 High Volatile coals—

average----- 2470°F.
highest ----- 2864°F.*
lowest ----- 2091°F.**

*A Pittsburgh bed coal W. Va., Fairmont District.

**A Pittsburgh bed coal Penna., Westmoreland Co.

12 High Carbon coals—

average----- 2435°F.

highest ----- 2785°F. D bed Cambria Co. Pa.
lowest ----- 2059°F. B bed Cambria Co. Pa.

Note. Among the high carbon coals, there was but one New River coal and no Pocahontas.

Of two coals, the one that makes the most clinker is not always the one that will give the most trouble from clinkering as it may make a large and heavy or a large and porous clinker that does not stick to the grates, while the other coal may make a thin glassy clinker

that will stick to the grates, stop up the air space and be difficult to remove. Coals which form a sticky clinker may often be burned without much trouble by spreading a layer of limestone over the grates after the fire is spread; the limestone cannot be fused and will keep the clinker from adhering to the grates.

It has been the writer's experience that the worst clinker to handle is formed from a comparatively low ash coal, with high percentages of lime and iron oxides, some of this clinker (that next to the grates) being jet black and looking like tar.

An analysis of such clinker and of the coal from which it came, is given as follows:

Coal

Moisture -----	.496	per cent
Volatile Matter -----	19.139	"
Fixed Carbon -----	73.530	"
Sulphur -----	.48	"
Ash -----	6.36	"

Clinkers

Top clinker reddish-brown, rough surface.	Bottom clinker, jet black, polished surface.
Silica -----	43.24
Alumnia -----	23.74
Iron Oxide -----	10.64
Lime -----	16.44
Magnesia -----	2.88
Undetermined -----	3.06
	34.80
	23.30
	11.64
	23.50
	3.65
	3.11

The top clinker was the ordinary clinker as usually formed from this coal, except that it was heavier and not so porous. The bottom clinker was thin, soft and pasty when hot and ran down through the air spaces in the grates in long, black threads, reaching all the way to the ash pit, so that it was impossible to get the slice bar

under it and it had to be chipped off the grates when cold, with a chisel bar.

It should be noted that the varying amounts of the fluxes, (lime, etc.) and their relation to each other is very complicated and little understood. Dr. Seger has shown (E. G. Bailey) that while the addition of a certain amount of such substances up to a certain point will lower the fusing temperature, increasing the amount will make a higher fusing temperature.

In this connection, attention is called to the buying of coal on specifications, many such contracts penalizing heavily for excess of sulphur over guarantee, on account of its supposed clinker-forming tendency. The writer was asked recently for an opinion on a contract of this kind which read: "for every one per cent of sulphur or fraction thereof above the guarantee (0.9 per cent) five times such percentage may be deducted from selling price." This is all wrong and extremely unjust. The sulphur in this case might easily run to 2 per cent or more without causing any perceptible loss in efficiency of the coal. Yet this contract was issued by the largest company of its kind in this country and called for 60,000 tons.

The intensity of combustion of the coal has much to do with the formation of clinkers, and coals that will clinker badly under some furnace conditions, will clinker very little under others. It would take an extremely hot fire to cause clinkers to form from a coal, the fusing temperature of whose ash was over 2800 degrees F., while a coal with an ash fusing temperature of 2250 degrees F. would fuse under ordinary conditions.

The method of firing may also have much to do with the formation of clinkers; the fireman who carries a heavy fire and is continually using the slice-bar, thus bringing up the temperature on the grates by turning

his fire up-side-down and having freshly ignited coal at the bottom, will surely have more clinkers and harder work cleaning fires than the man who is satisfied to let the ash stay where it belongs, on the grates, who only levels his fires to fill up holes or break a bank of coke and who uses the slice-bar only when removing clinkers and cleaning fires.

To prevent clinkers from adhering to the grates steam may sometimes be used by blowing it under the grates.

The use of crushed limestone or oyster shells spread over the clean fire, as soon as it is startd after cleaning, will always help to prevent clinkers from reaching and adhering to the grates, as stated above.

An instance of the use this method is given in Bulletin No. 235 United States Geological Survey, describing tests of two different coals. On the first test of these coals, without using limestone, it took forty-five and thirty minutes respectively to clean fires, while in the second tests, using limestone, as described above, it took but eight and ten minutes for each cleaning.

The oyster shell "method" was observed by the writer at a steam plant in tidewater Virginia. The coal used clinkered badly and on examination the surfaces of the lumps were seen to be covered with whitish brown scales of carbonate of lime, a sample of which yielded the following analysis:

Silicia	-----	.375
Alumnia	-----	.100
Iron Oxide	-----	1.55
Lime	-----	86.82
Magnesia	-----	2.118
Alkalis and undetermined	-----	9.036

The clinkers formed were thin but stuck closely to the grates and it was found necessary to shut the plant down to clean the fires. After cleaning was completed and a

new fire built, the old negro fireman procured a lot of oyster shells and spread them in a thin layer over the fire. At the end of the day's run, the fires were cleaned easily and the clinkers had not adhered to the grates. (F. R. Wadleigh, COAL AGE, 1912.)

Sulphur.

Sulphur is found in all coals, in amounts ranging from as low as 0.2 per cent to as high as 7 per cent; samples of two Brazilian coals showed 12 and 14 per cent.

Sulphur in coal may occur in three different forms.

1. As organic sulphur, where it is a constituent of organic compounds forming a part of the real coal substance and in combination with the carbon compounds distilled off with the volatile matter when the coal is burned or heated.
2. In combination with iron, as the commonly known "Iron Pyrites", iron disulphide, or as marcasite.
3. As calcium sulphate or as sulphate of iron; the latter forms showing when the coal has been exposed to weathering, usually as a whitish-brown scale or coating on the coal surface.

Sulphur Undesirable Element In Coal.

Sulphur is an undesirable element in coal, but its bad effects have often been greatly over-estimated.

1st. As regards its being responsible for clinkering of coal, a widely accepted idea; it has been clearly and decisively proved that the amount of sulphur in coal has little or nothing to do with its clinkering tendency.

A study of the results of ash-fusing temperature determination, as reported by the U. S. Bureau of Mines will show this. For instance, coals with as much as 3 per cent sulphur will have an ash-fusing temperature of

as high as 2800°F., practically non-clinkering, while another coal with 0.6 per cent will show an ash-fusing temperature of 2100°F. and will clinker badly.

In the writer's experience the coal that made, in actual combustion under boilers, the worst clinker, both in amount and nature, contained but 1.00 per cent sulphur.

Take coal from the No. 3 Pocahontas bed of W. Va. for instance; there are given 246 samples from 66 mines, with the average sulphur percentage 0.59 ranging from 0.95 to 0.43, while the ash-fusing temperature averages 2440°F. varying from 2210°F. for a coal with 0.45 sulphur to 2820°F. for coal with 0.77 per cent sulphur.

It is of course true that many coals with high sulphur content do clinker readily, but it is not because of the high sulphur content alone; it is equally true that in some regions the clinkering property follows the percentage of sulphur to a considerable extent, but in the latter cases, it is generally not the sulphur alone, but the iron content of the ash which often has an effect upon the fusing temperature, the percentage of iron generally increasing with the increase in sulphur content.

Sulphur, Effect On Industrial Use of Coal.

The foregoing statements apply to steam coals used under boilers more especially; when we come to coals for making gas, coke, and for other industrial uses, sulphur is a most undesirable element on account of its effect upon the product.

In making illuminating gas, a low sulphur coal is required today, as the gas from a high sulphur coal will contain sulphur compounds, such as sulphuretted hydrogen and other undesirables, which must be removed from the gas before it can be distributed.

In coke making and in metallurgical furnaces, sulphur in coal is not wanted on account of its effect on the iron or other metals.

Sulphur has often been held accountable for spontaneous combustion in coal, a theory generally discredited today, except as it may be a contributing element in such action.

(See further discussion of the effect of sulphur content under "Coal for Coke Making" and Spontaneous Combustion in Coal.)

Sulphur, in addition to the shape in which it occurs in coal, may be classified as—

Non-combustible sulphur (pyritic sulphur), that portion left in the ash and clinkers after coal has been burned.

Volatile organic sulphur, the portion that escapes when coal has been burned or carbonized.

Sulphur, Effect On Boilers and Furnaces.

The effect of sulphur in coal on boiler furnaces and fittings is a matter often discussed and is thought by many to be of some importance; a fact seldom mentioned in this connection is that only the combustible sulphur can cause corrosion of boiler heating surfaces, hence the total sulphur is no basis for determining the possibility of corrosion.

Hydrogen.

Hydrogen is one of the gaseous elements found in coal, its percentage being determined in the ultimate analysis, as shown elsewhere; it is included in the moisture, fixed carbon and volatile matter of the proximate analysis.

The amount of hydrogen in coal varies from 2 per cent in anthracite coals to over 6 per cent in some of the highest volatile bituminous coals; some cannel coals contain as much as 7.1 per cent.

The heating value of hydrogen is 62100 B. t. u. but not all of the hydrogen is available for combustion, part of it combining with oxygen to form the steam (water) given in the combustion of coal which, together with the water in the coal, is lost.

Carbon in coal as determined by the ultimate analysis, is the element carbon, which has a heating value of 14500 B. t. u. and is one of the two principal elements from which coal derives its heating value in combustion, all of its heating value being available for combustion. But, coals with the highest carbon percentage are not always those having the highest heating value, contrary to a quite common belief among coal users and producers.

Nitrogen.

The amount of nitrogen found in coal is small, varying from 0.4 per cent to as high as 2.5 per cent. As a rule, the anthracite and semi-bituminous coals contain the smallest percentages of nitrogen; the highest nitrogen coals in this country are found in Eastern Tennessee and in certain seams in Washington, coals from these fields varying from 2 to 2.4 per cent. Certain South African coals also contain as high as 2.45 per cent.

Nitrogen is a neutral element in combustion; it will not burn nor will it support combustion.

It is from nitrogen that we derive, however, one of the most valuable by-products of coal, ammonia in its various forms, especially ammonium sulphate (N H₃) so much in demand as a fertilizer.

In the coking process in by-product ovens, we obtain a maximum of 28 lbs. of ammonium sulphate per ton of coal; in the gas-making process, the yield is as much as 30 lbs. of sulphate.

In neither of these processes is all of the nitrogen in the coal recovered as ammonia, part of it, varying from 40 to 55 per cent, remaining in the coke, not more than 20 per cent being recovered as ammonia.

There is, however, another commercial process that does recover practically all of the nitrogen in the coal as directly proportional to the amount of nitrogen in the coal, it is claimed.

"Mond" System of Ammonia Recovery.

This process is known as the "Mond" System for generating producer gas, with ammonia recovery, Dr. Ludwig Mond having been its originator. (See "Gas Producers.")

Oxygen.

Oxygen is a constituent of all coals in varying amounts, from as low as 2 per cent in the best steam coals to 20 per cent in inferior grades and 40 per cent in lignites.

There is no satisfactory direct method of determining the exact oxygen content of coal, so it is computed by subtracting from 100 the total of the percentages of carbon, nitrogen, sulphur, water and ash.

"The result so obtained is affected by all (or any) error incurred in the other determination (of other substances) especially by the change in weight of the ash-fusing constituents of the coal on ignition." (American Society for Testing Materials, 1918.)

"There is no direct method for the estimation of oxygen in coal. In an ultimate analysis, the percentages of carbon, hydrogen, nitrogen, sulphur and ash are added

to the difference between this sum and 100 per cent is called oxygen. It is thus apparent that any errors in the estimation of the other constituents are reflected in the figures for oxygen and that therefore this figure is to be regarded as the least significant of the analysis." (A. H. White, "Gas and Fuel Analyses", McGraw-Hill Co. 1918.)

The anti-calorific effect of oxygen in coals was closely studied by Mr. David White, of the U. S. Geological Survey and the results of his investigation were published in Bulletin 382, afterwards reprinted as Bulletin 29, by the Bureau of Mines in 1911.

As a result of these investigations, Mr. White concludes that oxygen and ash of very nearly equal anticalorific or negative value, ash being probably slightly more injurious in most coals.

This conclusion has never been actually contradicted or disproved and is generally upheld today, although another Bulletin (No. 135, page 83) apparently holds that it is not definitely proved in actual combustion in the furnace, saying "At the present state of knowledge of combustion of coal it is difficult to explain why oxygen when contained in the volatile matter should delay its combustion. Nevertheless there are some indications that volatile combustible containing a high percentage of oxygen is harder to burn than one containing little oxygen. Whether the difficulty in burning it is due to the oxygen content or to some other chemical property cannot be stated definitely."

There seems to be no proof or logical reason that oxygen in coal should cause incomplete combustion and it is possible that decreased combustion efficiencies may be due to other constituents such as high moisture and ash.

Heating Value.

The heating value of fuels, including coal, is usually expressed in terms of heat units per unit of fuel.

In this country, the heat unit usually applied to coal and coke is known as the British Thermal unit, abbreviated b.t.u., the heating value being given as the number of B.t.u.'s per pound of coal.

B.t.u. Definition of

A B.t.u. is defined as the amount of heat necessary to raise the temperature of one pound of water, at its maximum density, one degree Fahrenheit. Or, more accurately, $1/180$ of the heat required to raise the temperature of one pound of water from 32° to 212° Fahrenheit.

The heat unit used more generally abroad in countries where the metric system is used (the B.t.u. is largely used in England also) is the **calorie**, which is defined as the amount of heat required to raise the temperature of 1 kilogram of water from 15 to 16 degrees Centigrade.

A calorie, when used as the measure of the heating value of coal or coke, is the number of units weights of water the temperature of which may be raised 1°C by the combustion of one unit weight of the fuel such fuel unit being 1 gram, 1 kilogram or 1 lb. Used in this way, a calorie is equivalent to 1.8 B.t.u.

Determination of Heating Value.

Actual determination of the number of heat units in coal is made with an instrument called the calorimeter, of which there are several types, the most accurate being known as the bomb calorimeter, with its several modifications, all based on the same principle.

The bomb calorimeter may be briefly described as consisting of a combustion chamber in which the fuel

is burned in oxygen, a vessel containing a known weight of water, in which the combustion chamber or bomb is immersed, with thermometers for measuring the rise in temperature of the water after combustion has taken place.

Value and Use of Heat Unit Determination.

Determination of the calorific value of coal in the calorimeter gives an accurate measure of the heat it is capable of giving forth, when burned with the exact amount of oxygen required for combustion and is thus an indication of the heating value of the coal in actual combustion in furnaces.

Coals with the greatest amount of combustible matter will of course, in the calorimeter, yield the greatest heating value, consequently low ash content means high heating value.

But there are other items besides ash that effect heating value, the character and amount of volatile matter in the coal having much to do with heating value.

The higher volatile coals contain more hydrogen, which has a greater heating value than carbon (hydrogen 62100 B.t.u., oxygen 14500 B.t.u.) but, only a part of the hydrogen is available for combustion and that part is much more difficult to burn than is the carbon, most of the latter being fixed or in a solid state, while the hydrogen is of course, gaseous and is rapidly evolved in combustion of the coal, making it much more difficult to effect its combination with the oxygen required for its perfect combustion.

When the percentage of volatile in the coal substance (coal free from ash and moisture) reaches around 20 per cent, then, although the percentage of carbon increases

and volatile decreases, the B.t.u. value also decreases, so that the anthracite coals, although at their best, almost pure carbon, will not yield as great heating value as will the semi-bituminous coals, with a lower carbon content, such as Pocahontas or New River or the Welsh steam coals.

Calorimeter Determination Not Always Measure of Actual Value of Coal.

While the heating value of coal as shown by the calorimeter determination may be considered as accurate, within a limit of 50 B.t.u plus or minus it cannot always be taken as an accurate measure of its practical value in furnaces, as there are other factors that must be considered, an important one being the character of the ash. A badly clinkering ash will more than offset high heating value, as it will prevent good combustion and hence lower the number of heat units that can be turned into useful work.

Calorimeter Tests, Condition of Samples.

In giving the heating value of coal as expressed in heat units, distinction must always be made as to the conditions of the calorimeter test and of the coal sample tested, whether on

- Coal, as received,
- Coal, air dried,
- Coal, dry basis,
- Coal, ash and moisture free, or combustible.

It is obvious that coal as received, or without drying, will contain less heat units than will dry coal.

Coal "as received" means with the amount of moisture contained when it reached the laboratory.

Coal "air dried" contains the moisture left after the sample has been dried in the air at a temperature of 30 to 35°C. usually for 12 hrs. It is this air dried sample that is actually used by the chemist in making the analysis. The loss in moisture is reported as the "air drying loss."

Coal, "dry basis" is reported when sample has been dried at 212°F. usually done in a special furnace, over a period of one hour.

The term coal "as fired" is used in reporting results of boiler tests and means coal as sampled in the boiler room; it may be quite dry or moist, depending on local conditions.

The commercial rating of coals by their heating value may before long become entirely a thing of the past. Even now, coals for the carbonization processes, coke-making and gas making, are not rated according to their B.t.u. value, but largely by the yields of the various products and by the comparative amounts they contain of certain constituents that have little or nothing to do with heating value, such as sulphur and phosphorus.

The day is coming when we shall value most highly the high volatile bituminous coals, with their rich yields of tar oils and gases when the low-volatile semi-bituminous coals will be used only for making steam. Even today, the coal lands that bring the highest prices are those containing the medium volatile coking and gas coals, with 30 to 34 per cent of volatile matter.

We may even see the dream of the Sheffield (Eng.) colliery owner come to pass; that his colliery had but one railroad siding and that only for bringing in pitwood and supplies; with two pipe lines going out, one for oil and one for gas.

CHAPTER V.

USES OF COAL.

Coal for Steam-Making.

By far the largest consumption of coal is in the various and varied plants for making steam, locomotive and stationary, marine and land.

Any and all kinds of coal can be used and are used for this purpose, from lignites to anthracite, with varying results and in different ways.

According to the estimates of the U. S. Geological Survey, the industrial steam trade uses about 33 per cent of the total production; the small steam users and domestic consumers use another 16 per cent.

But while almost any kind of coal can be used under boilers; the nature of different steam plants and their equipment must be carefully considered, when selecting coal for such use.

It is obvious, therefore, that no definite rule can be followed in selecting a steam coal for use at any given plant; the coal that will make the most steam for the least money is the one to select, other things being equal.

ANALYSES OF SOME STEAM COALS.

The following analyses of some of the best known "steam" coals are given as typical of the best grade.

POCAHONTAS AND NEW RIVER COALS

	Moisture	Volatile	Fixed Carbon	Ash	Sulphur	B.t.u.	Ash Fusing Temp.
1. Pocahontas Run of mine--	Dry	19.07	76.00	4.93	0.61	14960	2560° F.
2. Pocahontas Run of mine--	Dry	18.56	74.80	6.14	0.68	14751	2600° F.
3. New River Run of mine--	Dry	20.20	75.96	3.83	0.75	15074	2600° F.
4. New River Run of mine--	Dry	20.32	74.00	5.58	0.82	14789	2600° F.
All Analyses by U. S. Bureau of Mines.							
1. Average of 111 samples from 27 mines.							
2. Average of 4905 samples from actual shipments.							
3. Average of 181 samples from 55 mines.							
4. Average of 3206 samples from actual shipments.							
<u>PENNSYLVANIA STEAM COALS</u>							
Best Run of mine -----	23.25	70.37	6.38	1.42	14648		
Best Run of mine -----	16.81	77.62	6.57	1.07	14787		
Second Run of mine -----	15.98	75.20	8.82	1.35	14315		
<u>GREAT BRITAIN</u>							
Scotland							
Aitkens Navigation, Large--	24.47	70.61	4.92	0.86	14785		
Lochelly Navigation, Large -----	26.12	78.88	2.97	0.61	14590		
Yorkshire							
Barnsley, Best Steam, Large	32.35	64.56	2.59	0.90	14616		
Barnsley, Washed steam--	32.26	33.46	60.45	2.83	0.78	14384	

DURHAM AND NORTHUMBERLAND STEAM COALS

Best Large -----	28.87	67.67	3.00	0.86	14887
Durham, Best unscreened -----	31.45	63.67	4.57	0.71	14580

ANALYSES FROM "SOUTH WALES COALS," L. J. DAVIES, 1920

Moisture	Volatile	Fixed	Ash	Sulphur	B.t.u.
Unscreened Steam -----	1.67	16.99	70.80	10.54	1.89
Unscreened Steam -----	1.48	22.46	65.47	10.59	2.19
Smalls, best -----	1.01	11.54	76.64	10.81	0.89
Smalls, 2nd class -----	1.17	14.02	69.49	16.32	1.11
Smalls, best -----	1.31	15.15	70.93	12.62	0.89

ANALYSES SOUTH WALES STEAM COALS

Best Admiralty, large -----	0.83	16.63	78.84	3.70	1.08	15001
Best Admiralty, large -----	.72	15.22	80.60	3.46	0.89	15244
Best Admiralty, large -----	.94	11.74	83.67	3.65	0.81	15215
2nd class Admiralty, large--	1.46	15.75	77.94	4.84	1.04	14798
2nd class Admiralty, large--	1.46	16.76	77.94	4.84	1.04	14798
Best Monmouthshire, large	2.13	29.13	63.24	4.90	0.56	14750
Eastern Valleys, large -----	0.86	27.34	65.54	6.26	0.73	14634
Western Valley, large -----	1.93	24.91	66.97	6.14	1.19	14760

GERMANY

Westphalia, large -----	1.4	22.0	73.0	3.6	1.1	14409
Hannibal, large -----	1.8	17.1	76.0	5.6	1.3	14065
Victor, Nuts -----	1.6	17.0	76.3	6.1	1.0	14163
Konigsborn, large -----						

Locomotive Fuel.

For locomotive fuel, the best coals in this country are considered to be the medium high volatile coals of the Eastern coal fields, from the Pittsburgh and Fairmont districts, from East Kentucky, Southern Virginia and West Virginia; some of the Ohio and Illinois coals are also excellent for this purpose.

For a long time it was considered that the low-volatile "steam" coals, such as Pocahontas and New River, were the best for steam making on locomotives, as they are at stationary steam plants, but now coals of that nature are not much used by railroads in this country, except where the prevention of smoke is required by law or where their use is dictated by mine location or policy.

The principal reason for this change was due to the realization that higher rates of evaporation could be maintained with the higher volatile coals, or in other words, that they would make more steam per unit of heating surface in less time, an important consideration in locomotive operation.

Requirements of Locomotive Coal.

The general requirements of a good locomotive coal are:

1. Capability of burning at high rates of evaporation and combustion.
2. A fairly low ash content, not to exceed 9 per cent; high ash-fusing point, not under 2500° F.
3. It should be fairly hard and lumpy.
4. It should coke to some extent.
5. Preferably, the volatile matter should not exceed 35 per cent.
6. The inherent moisture or water of composition content should be low, not to exceed 2.5 per cent.

Locomotive Fuel In R. R. Operation.

Locomotive fuel is one of the most important items in

railroad operation and its purchase should be given careful consideration, with a view to obtaining the most suitable and economical coal that price and delivery will warrant.

The importance of the railroad fuel market to the coal seller and mine operator is shown by the fact that, in 1920, the Class 1 steam railroads purchased 155,343,635 net tons of bituminous coal.

SIZE OF LOCOMOTIVE COAL.

Little accurate data is obtainable on this point, but there seems no doubt that the question of size depends largely on the description of coal to be considered, whether low or high volatile, coking or non-coking.

With low volatile coking or semi-coking coals, run-of-mine will generally give the best results, if hand-fired; with stokers, the smaller sizes, such as nut and slack are preferred, partly because stokers will not handle large lumps. With the harder high or medium high volatile coals 28 to 36 or over, sized coals give somewhat better results.

Tests made in 1917, at the University of Illinois experiment station, on a Mikado type locomotive, hand fired, gave results as follows, the tests having been made to determine the steam producing qualities of different sizes.

At medium rate of combustion—

Run of mine -----	100
3"x6" Egg -----	102
2" Lump -----	99
2"x3" Nut -----	98
2" Screenings -----	93
1½" Screenings -----	85

At high rate of combustion—

Run of mine -----	100
2"x3" Nut -----	106
3"x6" Egg -----	105
2" Lump -----	97
Screenings -----	87
Screenings -----	82

These tests, it should be stated, were all made with Illinois coal, from one mine.

Large lumps and run-of-mine (containing large lumps) must be broken up by the fireman and probably, if the coal is hard and difficult to break, will take so much time and labor to break, that the fireman finds it difficult to keep the fire uniform, especially when the locomotive is working hard.

USE OF COAL ON LOCOMOTIVES

The Fireman.

The effective carrying out of all plans and schemes for the economical use of fuel on locomotives comes to depend finally on the interest, cooperation and skill of the engine crew but, upon all factors affecting fuel consumption, the fireman has the greatest influence. His work can spoil or render ineffective the best coal and the most efficient design of locomotive; on his intelligence and industry depends largely the expenditure of \$672,891,964,000 (paid by R. R. in U. S. for coal in 1920), equal to 10.9 cents out of each dollar of operating revenue. He may, by the exercise of his utmost skill and intelligence, turn into steam 80 per cent of the heat value of the coal, or by careless firing and ignorance, may easily waste 30 per cent of the best units in the coal, and only utilize 50 per cent. Of course, the quality of the coal and the design, condition and tonnage rating of the

locomotive, have much to do with results obtained by the fireman, but skilful firing and handling of the locomotive can very largely neutralize poor design and overloading, just as good coal can, and is often made to, overcome poor condition of the locomotives.

There is more coal wasted by careless firing than in any other one way and while some firemen are better than others, no man of ordinary intelligence can afford to do anything but his best. Careless firing and lack of interest in getting the best results out of the coal entrusted to his use, will always re-act on the man himself and make him careless in other things. The fireman should look upon the coal as so much money entrusted to his care by his employer, to be used in the most careful and intelligent manner and from which he is to get the greatest returns. A good fireman is a skilled workman and should be ashamed to turn out poor work, just as a really skillful mechanic is: the difference to the employer, in dollars and cents, between a good fireman and a poor one is certainly much greater than that between a good machinist or mechanic and an inferior one.

Suggestions On Use of Coal On Locomotive.

Anything in the way of written or printed suggestions that will help the fireman in his work will not only be of value to the man but also to his employer, the railroad; it is hoped that the suggestions following, gathered from practical experience and study, will be of assistance to both.

Both Engineman and Fireman should remember that such instructions are given them to think about and to find reasons for, themselves, so that they may be applied to varying conditions, as it is obviously impossible to give

reasons and detailed instructions covering all points and conditions applying to fuel consumption without going into the matter at too great length.

The railroad officials must bear in mind that the mere giving out of such instructions is not sufficient in order to get results. They must see that the rules given are carried out here, there and everywhere, not only on fast passenger trains but on slow freights. Everyone connected with the handling of locomotives should have copies of such instructions and be made to take an interest in their being carried out. The Trainmaster, as well as the Road Foreman or Travelling Engineer, should know the importance of the subject and should see that any firing instructions issued are carried out just as much as the train rules are.

"Eternal vigilance is the price" of fuel economy as well as of other desirable things, including "liberty." In fact, one of the requirements of true liberty is the right of a man to do his work in the best possible way and no man, fireman or engineman, has any right to the blessings of liberty and organization unless he can feel that he is doing his best with the material and equipment given him to work with.

Conditions of Locomotives As Affecting Coal Consumption.

But if the railroads expect their engine crews to be interested in fuel saving and insist on their carrying out reasonable and proper instructions to that end, they must keep in good condition all appliances affecting the use of fuel. It is not very encouraging to a fireman to know that a hundred or more flues are stopped up on his locomotive, that the engineman reported "clean flues" on the work report book and then to find, on going out

on the next trip, that small holes have been bored through a few bottom flues and that the rest are as bad as they were on the previous trip.

It is such occurrences (and they are not at all uncommon) that are largely responsible for the lack of interest and care shown by engine crews in the matter of fuel economy. Where one finds a road that keeps the flues clean and firebox and arches in good order, that doesn't have steam leaking around piston rod and valve stem packing, that keeps valves square and cylinder packing tight, etc., there will also be found a road whose men take an interest in the fuel question.

Waste of Fuel.

The railroad management, in one way or another, is just as much to blame as the engine crews for fuel waste, and with all our much talked of superiority in transportation methods and efficiency, we must take a back seat when fuel economy is mentioned, as compared with the results formerly obtained in European and South American countries, where the firemen are properly instructed and made to carry out their instructions.

There are several ways in which locomotive fuel is wasted with which the engine crews have little or nothing to do. Careful tests made not long ago showed that not less than 15 per cent of the fuel supplied to locomotives performed no part in actual moving of trains, but was accounted for in other ways, for nearly all of which the transportation and motive power officials were accountable. For instance, keeping more locomotives in service than are needed by business requirements, delays in yards and at meeting points, unnecessary stops, ordering locomotives out before they are needed, carelessness in cleaning and building fires, doubling hills due to too

heavy trains (which may cost from a half to a whole ton more than going up the hill once), schedules divided up without taking into consideration the grades and curvature of the road, etc. Every 15 or 20 minutes delay may cost from 500 to 1000 lbs. of coal, according to the state of the weather, condition of the locomotive, etc. In fact, everyone, from the general manager to the brakeman and the wiper, each and all affect, by their work, the coal consumption of locomotives.

Where the Heat From Coal Goes On a Locomotive.

Tests carefully made under direction of Prof. Goss showed the following results, using a good Pennsylvania or West Virginia coal, (Bulletin 402, United States Geological Survey.)

	Percentage of total heat in Coal	
	Used	Lost
Absorbed by water in the boiler -----	52	
Absorbed by steam in the super-heater -----	5	
Lost in vaporizing moisture in coal -----		5
Lost through discharge of Carbonic Oxide gas		1
Lost through the heat in gases going out of stack -----		14
Lost by unburned coal in front end cinders--		3
Lost by unconsumed coal thrown out stack as sparks -----		9
Lost by partly burned coal in ashes and clinkers -----		4
Lost through radiation of heat by boilers and cylinders, leaks of steam, water, &c.		7
	<hr/>	
	57	43

Now this statement applies to the locomotive only when running and not blowing off steam and it does not include the coal used while standing, starting fires and switching. Prof. Goss states that about 20 per cent of the

total locomotive fuel is used in the ways just mentioned, or is left in the firebox at the end of the run; so that the heat balance given accounts for about 80 per cent of the total fuel.

LOCOMOTIVE FIRING

Clinkers.

A coal that will make bad clinkers is one of the worst propositions the fireman has to contend with, but clinkering is often due to the fireman himself.

At a certain temperature clinkers will form from the ash of the coal; this temperature varies with different coals, but as soon as it is reached the clinker begins to form. Now this fusing point or melting point of the ash varies with the amounts of the different substances composing the ash, but there is, however, another item involved, the temperature of the fire at or near the grates. If this temperature is not as high as the melting point of the ash, then the latter will not fuse into clinkers. So, the hotter the fire and the more it is sliced and disturbed near the grates the more chance there is of having clinkers. So that the way in which the firing is done has much to do with clinkering; the man who carries a very heavy fire and is continually digging holes in it, thus getting green coal on the grates, turning the fire upside down and bringing the ash up into the hottest part of the fire, will certainly have more trouble than the man who is satisfied to let the ash alone where it belongs, on the grates, hooking the fire only in order to level the top.

Another frequent source of trouble from clinkers is not building up the fire properly before starting, allowing "green" coal to remain on the grates.

As every good fireman knows and every coal user should know, frequent slicing and stirring of coal fires will add considerably to the formation and spreading of

clinkers, especially if the coal has a comparatively low ash fusing point.

This refers of course to hand fired as distinct from stoker-fired locomotives, the former being still by far the most common method.

In fact, a good fireman can and often does show his skill by so handling a "clinkering coal" that he will have no trouble in burning it and keeping up steam.

Many railroad men interested in fuel handling will remember the heated discussion that arose many years ago, when the master mechanic of a well-known road in the middle west, read a paper before one of the railroad motive power associations, in which he claimed that no coal would clinker if properly handled and offered proof of it on his own locomotives, inviting every one interested to see his method and results. He made out a very good case and convinced a great many that his statements were true and that there should be no such excuse allowed for locomotive failures as "Poor coal."

Physical Impurities In Coal—

those that may be detected by the eye.

All persons concerned in the purchase and handling of locomotive coal should learn to know by their appearance the different impurities to be found in coal, such as slate, bone, iron pyrite, fire-clay. Knowledge of these impurities is of value, as by throwing them aside, better results may be obtained from the coal and less ash and clinkers produced. The effect of the different impurities on the burning of the coal should be watched, as all such knowledge tends to more economical results.

There is, of course, a vast difference among different coals in the amounts of such impurities; some coals are apt to have considerable slate, others slate and bone, etc.,

this difference being mainly caused by lack of proper preparation and inspection by the mine operator.

APPEARANCES OF IMPURITIES AND THEIR EFFECT ON THE FIRE

Slates.

Slates are of irregular shape, generally more or less flat, are heavier and harder than the coal and vary in size. Their color runs from a light gray to black, some of them are soft and easily broken, while others are very hard.

Their effect on the fire is to add to the amount of ash and refuse; they take up space on the grates that would otherwise be occupied by coal and they also add to the size of clinkers. Slates have no value as fuel.

Bone and Bony Coal.

Bone may be called a slaty coal or a carbonaceous slate. It is really an impure coal and the slate or sandstone in it is not in layers but in small particles mixed with the coal. It is harder and heavier than the coal, of a dark color and usually breaks into irregularly shaped pieces. Sometimes it will be found in small pieces separate from the good coal and sometimes it shows as a layer in the large lumps, just as it comes from the seam of coal.

Its only effect on the fire is to add to the amount of ash and to take the place of better fuel, but it will not clinker.

It has considerable fuel value, varying in this respect, usually the harder it is, the less is its fuel value; analysis shows that it may contain from 15 to 25 per cent ash, while the clean coal may not have over 7 per cent.

Fire Clays.

Fire clays come in small pieces or layers in the coal, sometimes soft like putty and are generally of a light gray or reddish gray color. They are usually found below the seam of coal, but sometimes in the middle in layers or partings. They add to the amount of ash and clinkers and have no value as fuel.

Iron Pyrites.

This substance is of a bright yellowish color, resembling gold or brass, coming sometimes in thin layers or in flakes, sometimes in hard, round or partly round, balls, often in lumps more or less mixed with the coal. It has no practical fuel value and is a detriment to the coal in every way. Some coals contain very little pyrites, only a few small flakes occasionally on the surface of the lumps, while other coals are full of it.

Mixing Coals.

It frequently happens that more than one kind of coal must be used on locomotives on the same division or run. This is a matter over which the engine crews have no control, of course, but it is responsible for a large amount of trouble and reports of "Poor coal"; it should be the practice on every road to avoid, as far as possible, any mixing of coals on any one division.

Coals of the same appearance and nature, two different coking or semi-bituminous coals, such as Pocahontas and New River, or two different gas coals such as Fairmont and Tennessee or Kanawha gas and splint, will usually burn when mixed without any trouble, but coals of a different nature are very apt to give trouble from clinkers when mixed. Besides it is often the case that locomotives are drafted for one kind and consequently do not give good results with another coal; further, coals

of a different nature, such as gas or block or a coking coal, require different methods of firing.

That this mixing of coal is often detrimental to good results was shown some years ago on the Chicago & Northwestern R. R. when a remarkable improvement in engine performance was shown by a change in distribution of coals, so that each principal division was given one kind of coal exclusively; other roads have had similar experiences.

Wetting Coal on Locomotives.

The wetting of coal is such a universal practice on locomotives, as well as at many stationary plants, that a discussion of the reasons for and against, should be of interest and help.

In the first place, coal will always be "wet down" on locomotives in order to keep dust from flying, as a matter of comfort to the men on the engine, if for no other reason.

It is claimed that coal should not be wet because:

1st. Any moisture or water in the coal must be evaporated in the firebox and this takes heat which is therefore lost, as the water must be raised to a heat of 212° , when it is evaporated into steam which must be raised to the heat of the gases in the firebox.

2nd. Water in the coal is turned into steam, which takes up valuable space in the firebox that would otherwise be occupied by the hot gases from the coal; this reduces the draft. The steam from a given quantity of water takes up nearly 1800 times the space or volume that the water did, at the ordinary pressure and temperature of the atmosphere.

3rd. If the water is separated by the heat into gases, oxygen and hydrogen, their combustion gives no gain, as

the heat it takes to separate them is just as much as will be gained by burning them.

On the other hand, the reasons given for wetting coal may be summed up as follows:

- 1st. The comfort of the men on the engine.
- 2nd. The coal is held together, especially if there is much slack, which prevents fine coal from being drawn out through the flues before it touches the fire; if a coking soft coal, it will coke more readily and made a better fire.
- 3rd. Water vapor or steam in the firebox aids (promotes) combustion, lengthens the blue flame of the burning hydrogen and carbonic oxide gases and the heat from burning these two gases more than makes up for the heat lost at first by separating the oxygen and hydrogen of the water.
- 4th. It keeps down smoke by restraining, or making slower, the evolution of gases from the coal giving them a better opportunity to mix with air, thus preventing, to some extent, the formation of smoke.

When coal is first thrown in the fire it gives off at once a large amount of hydro-carbon (gases composed of hydrogen and carbon) gases, which are usually given off faster than they can be brought into contact with the necessary amount of air for complete combustion. Now, if by wetting the coal we can hold back a little of this giving off of gases, an advantage will be certainly gained by the burning of this gas, high in heating power, some of which would otherwise pass out of the firebox unconsumed and make smoke.

5th. It prevents the loss of fine coal dust, which if dry, would be blown away or lost by the shaking of the locomotive.

The writer knows of no actual reliable tests made on locomotives to settle this question. Mr. G. H. Barrus, one of the best-known mechanical engineers in this country, in his book "Boiler Tests," gave the following data:

"In running a test of a double-deck horizontal return tubular boiler, using Georges Creek Cumberland coal, an amount of water equalling 5 per cent of the weight of the coal used was added to the coal before firing, the result showing an increase in evaporation of 3 per cent as compared with a test made on the day previous with dry coal. The coal used contained 6.7 per cent ash."

Mr. Barrus does not discuss the matter, merely making the statement given above.

Mr. G. R. Henderson, in his work on "Locomotive Operation," the most thorough study of the question yet published says:

"The practice of wetting coal is due to an effort to keep down the dust and also prevent the dry, fine stuff passing to the stack without being consumed—in this it is effective, but no more water should be used than necessary to effect this purpose, as all such water must be evaporated in the firebox and absorbs otherwise useful heat."

It is believed therefore, that apart from the question of comfort of the engine crew, it is a good practice to always wet the coal, so that it goes into the firebox moist, but not dripping wet.

It may be stated that there is quite a wide-spread idea among enginemen and firemen that wetting some coals will cause them to clinker. This idea is a wrong one. The only effect that wetting coal might have on clinkering would be to prevent its formation or to make it less troublesome. It is a common practice in stationary plants to blow steam in the ash pits to prevent clinkers

from adhering to the grates and also to keep the ash-pit full of water, partly for the same purpose.

SUGGESTIONS FOR A FORM LETTER TO ENGINE-MEN AND FIREMEN

Your attention is called to the importance of handling coal furnished the locomotives of this company with the greatest possible skill and intelligence, so that every pound may be burned to the greatest advantage. To show the importance of this subject, the following figures are given:

During ----- this company paid \$----- for the coal used on its locomotives. This means an average cost for the year, of \$----- for each of the ----- locomotives. As the average mileage for each locomotive during the year was ----- miles, this means an average cost per locomotive mile of -----cents for coal.

If, by the use of extra care and attention, you had run your locomotive one mile further to each ton of coal used, you would have saved the company \$----- during the year, besides saving yourselves the handling of ----- tons. We ask, therefore, that you give especial attention to the saving of coal, so that the company may be saved the needless loss of a large amount of money and yourselves be saved the equally useless labor and energy expended.

INSTRUCTIONS TO ENGINEMEN AND FIREMEN FOR THE ECONOMICAL USE OF COAL.

Issued by the Pennsylvania Railroad Company, in 1910.

1. Enginemen and firemen must work together so as to save coal and reduce smoke.
2. Enginemen and firemen when taking charge of a locomotive must see that the fire, grates and ash

pan are in good condition so as to prevent engine failures on the road.

3. Enginemen must include in their reports on M. P. Form 62 all defects causing leaks of steam or water in any part of the locomotive, as the repairs of these defects will avoid loss of coal.
4. The burning of bituminous coal in a locomotive requires air which must be admitted through the grates and through the fire door.
Smoke means waste of coal and must be avoided. Large quantities of coal placed in the firebox at one time cool down the fire, cause smoke and waste coal; small quantities at regular intervals will keep up steam pressure.
Lumps of coal should be broken in pieces not larger than three inches.
5. A bright and level fire over the whole grate must be carried whenever possible. When a sloping fire is used, no more coal should be banked at the door than is necessary.
6. To prevent smoke and to save coal, the fire door must be placed on or against the latch after firing coal or using the scraper, slash bar or hook, and when on sidings, in yards, at terminals or before starting.
7. Before the throttle is closed, the blower must be used and the door placed on the latch. Firemen must stop firing long enough before steam is shut off to prevent smoke and waste of coal.
8. Dead spots in the fire must be avoided when running with throttle closed, as this frequently causes flues to leak.
9. The grates must be shaken as often as is necessary to clear the fire of ash and clinker in order to admit sufficient air, and in such a manner as to avoid the loss of good fire. Care should be taken to place the grates level after each operation.
10. The waste of steam at safety valves must be avoided. One shovel full of coal is required to make the

steam that escapes from a safety valve in one minute.

11. The sprinkling hose attached to the injector must be used frequently to keep down dust on the foot plate and in the cab and to wet coal in the tender. However, too much water on the coal should be avoided as to some extent this practice is the cause of flues stopping up.
12. Coal must not be allowed to collect or remain on the foot plate, but should be swept into the coal space of tender, and not out on the tracks.
13. Engines must not be brought into terminals with a dead fire, which will cause flues to leak; nor with too heavy fire, which will cause waste of coal.
14. When banking or cleaning fires, the blower should be used as lightly as possible. After the fire has been cleaned of ash and clinker, the clean fire must be placed at the front end of the grates and maintained in good condition.
15. When cleaning fires or with a banked fire, excessive use of the injectors must be avoided, as this will result in injury to the flues.
16. After taking coal at coaling stations, the fireman must do the necessary trimming of coal pile, to insure the prevention of coal falling off of tenders while in transit, which is both wasteful and dangerous to passing trains, trackmen, etc.
17. Coal can be saved by the proper use of the injector in pumping locomotive regularly, and by taking advantage of every opportunity to fill boiler when not working locomotive to full capacity; also by using the injector to avoid the safety valves blowing off.
18. Coal will be saved by always working the locomotive (except when starting) with a full throttle when the cut-off is one-quarter of the stroke or greater; but if one-quarter cutoff with full throttle gives more power or speed than is needed, the reverse lever should be left at one-quarter cut-off and the throttle partially closed as needed.

ANALYSES OF TYPICAL LOCOMOTIVE COALS, UNITED STATES

Samples from shipments received by Railroads.

	Moisture	Volatile	Fixed	Ash	Sulphur	B.t.u. Ash	Fusing Dry Temp. °F.
Pennsylvania, Low Volatile--	0.68	21.28	69.88	8.26	1.28	14777	2900
West Virginia, Low Volatile--	1.92	17.95	75.93	6.07	0.75	14739	2450
West Virginia, Fairmont----	Dry	36.84	54.24	8.92	2.06	13874	2270
West Virginia, Kanawha----	1.19	36.55	56.03	6.22	0.66	14200	2600
West Virginia, Kanawha----	1.51	33.55	57.35	7.59	1.19	13957	2550
Virginia, S. W. Banner seam	Dry	36.23	56.53	7.24	0.57	14303	2490
Pennsylvania, Pittsburgh----	1.18	34.88	56.24	7.70	2.16	14267	2550
Pennsylvania, Pittsburgh----	1.20	31.59	58.02	9.19	1.44	14140	2550
Illinois, No. 6 seam-----	8.14	34.18	47.92	9.76	0.95	12926	2290
Indiana, Block -----	3.14	39.26	51.06	6.54	-----	13000	2390
Ohio, No. 8 seam-----	2.04	36.37	48.17	13.42	3.18	12864	2210
New Mexico, Gallup -----	8.25	29.91	51.46	10.38	0.64	12516	----

Coal for Steamship Fuel.

The coal used as fuel in boiler furnaces of steamships is usually called "Bunker coal," the name having been derived from the term "bunker," applied to the compartments near the boilers in which coal is stored until used.

While some coals are preeminently adapted for use as steamship fuel, almost any fairly good bituminous coal can be made to serve, even coals with as much as 20 per cent ash, although 15 per cent is generally considered about the limit, for ordinary bunker coal.

A really good bunker coal should have the following characteristics.

Volatile matter should not run over 30 per cent, and preferably lower, down to 15 per cent.

Ash content should not exceed 9 per cent.

Ash fusing point should not be less than 2500° F.

It should stand storage without any marked tendency to spontaneous heating.

Its heating value should be high, not less than 14000 B.T.U., the higher the better.

It should stow well, about 42 cubic feet of space per long ton of coal should be the minimum.

It should be sufficiently free burning to make stoking easy, without forced draft.

Bunker Coals, World's Best.

The best known bunker coals in the world are:

United States.

Low Volatile—Standard New River.

Standard Pocahontas.

Certain Pennsylvania steam coals from the South Fork district.

Other good bunker coals of the U. S. are:

Medium Volatile coals 28 to 33 per cent volatile.

Best Kanawha, W. Va.

Best E. Kentucky.
Best S. W. Virginia.
Best Alabama, Black Creek.
Best Pittsburgh.

Low Volatile.

Cambria Co., Pa.
Somerset Co., Pa.
Clearfield Co., Pa.

Maryland & Northern W. Virginia Steam coals.

Great Britain.

Welsh Admiralty, Large.
Northumberland, D.C.B's., Large.
Durham, Large and Unscreened.
Yorkshire, Barnsley.
Scotland. "Navigation" Coals.

Germany.

Westphalia, Steam, Best Large.
Silesia, Steam, Best Large.

Japan

Mijke

China.

South Africa.

Natal Navigation. Dundee.

Australia.

Hetton. Wallsend.

New Zealand.

Paparoa.

East Indies.

Ombilin.

Canada.

Nova Scotia, Sydney.

Vancouver, Wellington.

India.

Deshargur, Best.

Domestic Heating.

The proper heating of the buildings in which we live

and work is one of the most important problems of the day. Professor Bone, who has given the problem careful consideration, says, in a lecture delivered before the National Health Society on December 1918, at London:

"If it still be true to say that coal is the material source of the energy of the country—the universal aid—the factor in everything we do, a dictum which the War has abundantly confirmed, then it may be asserted, without fear of contradiction, that the health as well as the wealth of the whole community is intimately bound up with the proper use of coal in our houses and factories, whether in manufacturing operations or as a domestic fuel."

This statement, undoubtedly a true one as regards Great Britain is almost, if not quite, as true of conditions in this country.

To speak more particularly of house heating as distinct from the heating of office buildings and factories, we need greater education and knowledge regarding the proper heating appliances and methods as well as of the fuel to be used and the best way to use it.

Coal, of some kind or description, or its derivatives coke and gas, are by far the most commonly used domestic fuels; the annual consumption of coal for this purpose being about 100,000,000 tons, according to the U. S. Geological Survey reports.

Domestic Coals, Kinds In Use.

The kind of coal used varies according to location; anthracite in the New England and the Middle Atlantic States and bituminous coals in the rest of the country. Some anthracite is used of course, in the Middle West and Northwest and in the Southern States and the use of coke is fast growing wherever it is available. But there is still and will be for a long time, a vast amount of the bi-

tuminous coal used in our homes, in all the States west of the Ohio and in the South. The use of anthracite coal has probably reached its highest point; it is unlikely that its production will ever exceed what it is today, as the anthracite deposits underlie a comparatively small area and their end is in sight.

For a smokeless, clean domestic fuel, we must look in the future to the products of bituminous coal, either high temperature or low temperature coke and gas.

It is true that the so-called "smokeless" semi-bituminous coals of West Virginia are largely used in the states between Ohio and Mississippi and in those bordering on the Great Lakes, because they are almost smokeless when properly burned, give out an intense heat and will burn for a long period with little attention, and can be used in any kind of furnace, stove or range as well as in open grates. The Pennsylvania semi-bituminous coals are adapted to the same uses, but their actual use for domestic heating is comparatively restricted, owing, to some extent, to their close proximity to the anthracite region.

Coals of this type are, however, so valuable for other purposes, that it would seem better to keep them out of the domestic market.

The "splint" coal of West Virginia, Kentucky and Tennessee are much in demand in the Middle West and South for domestic use, as they are hard, blocky, screen well and stand handling with little loss, ignite readily and make a hot and cheerful fire. But they are smoky, distribute soot and gases in the atmosphere and their use is not economical or healthy; they are, however, cheaper than the semi-bituminous or anthracite coals and their consumption reaches a large tonnage.

The screened sizes of Illinois and Indiana coals as well as those of the States farther West are much used for domestic purposes, as the semi-bituminous coals of Arkansas.

Regarding the domestic fuel question, the U. S. Bureau of Mines has made a series of thorough and useful investigations and tests, the results of which deserve the widest publicity (which they have not been given, unfortunately). Some conclusions arrived at from these investigations are given herewith, as leading to the more economical use of domestic fuel, with the banishing of smoke and its ever attendant annoyances, menaces to health and destruction of property.

Let us add that architects and builders as well as makers of house-heating appliances have been largely to blame for the uneconomical and wasteful use of coal in our houses.

If the larger coal companies supplying the domestic trade would take half the trouble that they do with their steam trade to educate users, they would probably find it a paying proposition. Some of the by-product coke making companies have pursued a policy of education in their domestic fuel trade, with excellent results both to themselves and to the user.

When soft coal is burned in the ordinary house-heating furnace the coal is first reduced to coke by driving off the volatile matter, most of which escapes unburned; then the coke burns in the furnace and heats the house. Driving off the volatile matter unburned not only causes a direct loss of heat but causes a great deal of dirt in the furnace, flues, boiler room, and also in the outside atmosphere. Since the volatile matter in soft coals is of negative value so far as heating the house is concerned, it is better to use a fuel that does not contain volatile matter.

Such a fuel is coke. Most of the coke on the market for domestic heating is made in special furnaces by driving off the volatile matter. From this volatile matter are obtained gas, tar, and other by-products that have a high market value. Therefore, by converting the coal into coke in these special coking plants the volatile matter instead of being a nuisance, is turned into a source of national wealth.

Results of investigations of the value of different fuels, including coke, anthracite and soft coals of various kinds, as fuel for house-heating furnaces will be published in a separate bulletin by the Bureau of Mines. The results obtained thus far show that coke can be burned in house-heating furnaces much more efficiently than soft coal.

The results obtained with coke under a steam boiler of a size to supply 800 square feet of radiation are summarized in Table 2.

TABLE 2.

Results of Tests With By-Product Coke.

Proportion of boiler capacity developed Per Cent	Average between Firing Hours	Duration of Tests Hours	Overall Efficiency Per Cent
52	4	96	78
88	4	120	72
122	8	120	68

The table shows that more than 70 per cent of the heat in the coke was usefully employed in heating the house.

Some time ago the engineering experiment station of the University of Illinois made comparative tests of by-product coke, gas-house coke, Pocahontas coal and Illinois coal. The results of these tests were printed in Bulletin

No. 19, University of Illinois.

Table 3 gives a summary of results of tests with a boiler capable of supplying 800 square feet of radiation.

TABLE 3.

**Results of Tests of Various Fuels
In House-Heating Boilers.**

(Tests made at the engineering experiment station of the University of Illinois.)

	Efficiency of boiler and furnace Per Ct.	Fuel fired at each firing Pounds	Average interval between firing Hours	Rated Capacity developed Per Cent.
By-product coke -----	61.63	75	8.71	64.46
Gas-house coke -----	56.22	75	8.21	65.48
Anthracite -----	51.93	75	2.47	66.00
Ill. coal, Williamson Co.	48.00	75	2.92	64.04
Pocahontas coal -----	46.51	75	8.30	64.88

This table shows that with coke about 61½ per cent of the heat in the fuel was utilized in heating the house, whereas, with Illinois coal, only 48 per cent of the heat was utilized. Hence if the coal and the coke contained the same amount of heat, about 7¾ tons of coke will deliver as much heat into the house as 10 tons of the soft coal. In addition to this higher efficiency from coke, the furnace and boiler room are kept clean with less work and there is no smoke to pollute the atmosphere.

(Technical Paper 242, Bureau of Mines.)

ILLUMINATING GAS.

Manufacture of.

Illuminating gas manufacture from coal is a carbonization process in which the coal is carbonized in closed retorts, the gases distilled off, coke remaining as a by-product, together with tar, ammonia, etc.

The Process.

Coal is fed into firebrick retorts, commonly of D shaped cross-section and raised to a temperature of from 1740-2500 degrees F. by external heating, over a period of 6 to 12 hours, during which the gases are distilled from the coal and collected in a large pipe or hydraulic main, as it is called, and are then put through a cooling and condensing process and a water "scrubber" to remove the tar, ammonia, etc. The gas is then further purified to remove sulphur compounds, naptha, etc. and piped to the gas holder ready for distribution.

Quality of Gas.

Until the present time, the quality of illuminating gas as delivered for use has been measured by its light giving qualities, measured in candle-power, but now, with the use of incandescent burners for lighting and its extensive use for heating, cooking, etc., it is being rated according to its heating value; a more equitable standard for present day use.

By-Products.

The coke obtained in the gas making process is an important by-product, especially in foreign countries. While not suitable for metallurgical purposes, on account of its structure, it is an excellent domestic fuel and its principal consumption, outside of that used by the gas companies themselves, is for that purpose.

The tar and ammonia obtained are similar to the by-products of the coking process, although the yields are different in amount.

Coals for Gas-Making.

The best gas coals in this country come from Western Pennsylvania, West Virginia, Virginia and Eastern Kentucky.

Analyses of Typical Gas Coals are as follows:

In Great Britain, the Durham and Yorkshire gas coals are considered the best and are used for gas manufacture all over Europe.

The Australian Greta seam coal is of excellent quality for gas making and was used largely in South America for that purpose before the War.

The use of coal for the manufacture of illuminating gas is world-wide and is an important factor in the coal trade of this and every other civilized country. Its use for this purpose began in 1797, when Murdoch built his first small plant; the streets of London were illuminated by gas in 1813.

Today, in this country, about one per cent of our coal output is consumed at illuminating gas plants.

Typical Analysis of a First Class Gas Coal.

Volatile Matter, per cent-----	30 to 35
Carbon -----	80
Hydrogen -----	5.5
Oxygen -----	8.8
Nitrogen -----	1.5
Sulphur -----	0.8
Ash -----	3.4
B.t.u. per lb. coal -----	14400

Distribution of Constituents of Coal In Gas Manufacture.

As showing the approximate distribution of the different constituents of coal after it has been carbonized the following table is presented, the coal used being a good grade of gas coals, with the assumption that no losses take place. The figures are taken from "Modern Gas Practice," Alwyn Meade (J. Allan & Co., London, 1916.)

One ton of coal consisting of—

1792 lbs. carbon		
distributed as coke -----	1385.0	lbs.
" as coke breeze -----	107.0	"
" in gas, Co & Co ₂ -----	30.0	"
" in gas, hydrocarbons -----	130.0	"
" in tar -----	122.0	"
" as cyanide, &c. -----	18.0	"
123 lbs. hydrogen		
distributed in gas and tar -----	98.5	"
" as ammonia -----	1.0	"
" as water -----	18.5	"
" in coke -----	5.0	"
197 lbs. oxygen		
distributed as Co & Co ₂ in gas and		
in tar -----	49.0	"
" as water -----	148.0	"
34 lbs. nitrogen		
distributed in gas -----	11.8	"
" in coke -----	14.1	"
" in tar -----	1.0	"
" in ammonia -----	5.8	"
" as cyanogen -----	1.3	"
18 lbs. sulphur		
distributed as gaseous impurities and		
in liquid -----	6.0	"
" in coke -----	12.0	"
" in coke and breeze -----	76.0	"
76 lbs. ash		
2240 lbs.	2240	lbs.

Water Gas.

Of late years, the manufacture of gas for lighting and heating has changed considerably, due to the introduction of "water gas" manufacture, for which almost any kind of coal will serve, as well as coke. It is quite probable that the use of the so-called "gas coals" for the manufacture of "town" gas will show a considerable decrease each year, as water gas can be made more cheaply and

gives as good results in use with modern equipment.

Water Gas, Manufacture.

Water gas is the general name applied to a mixture of gases resulting from the decomposition of steam when passed through a mass of incandescent carbon. For lighting purposes, the mixture must be "enriched" by the addition of "gas oil" a petroleum product, the resulting product being called "carburetted" water gas.

"Blue" water gas is the uncarburetted water gas; it gives very high flame temperatures, up to 3000 degrees F. and is therefore of great value for various heating operations, especially for welding processes.

REQUIREMENTS TO BE CONSIDERED IN SELECTION OF COAL FOR GAS MANUFACTURE.

Volatile Matter.

Good gas coals should contain from 30 to 40 per cent volatile matter.

Ash.

A first class gas coal should contain not over six per cent ash.

Oxygen.

While considerable variation is shown in the amounts of various constituents of coal, it has been established by numerous experiments that good gas coals should contain approximately from 6 to 9 per cent of oxygen.

Suitability To Plant Conditions.

While there are certain standard specifications as to quality required for a first-class gas coal, as shown by analysis, the actual value of any coal for a given plant can be determined only by tests under commercial operation conditions. The suitability of any coal to the plant conditions and equipment is an

important item, just as it is in the selection of coal for steam plants.

Yields.

The yields of gas, coke and by-products from any coal must be considered in their relation to market conditions.

Some coals yield more and better coke than others; another coal may give high yields of by-products with less or softer coke, still another less ammonia, but a better quality of gas and tar.

Costs.

The delivered cost of different coals and its bearing on yields, market consumption and sales should be a ruling factor.

Gas Coke.

Gas coke is a by-product of the manufacture of illuminating gas; it is softer and contains more volatile matter than metallurgical coke. It finds its greatest use in domestic heating; the gas plants using considerable amounts themselves under boilers and retorts.

INDUSTRIAL FURNACES.

Coal for.

For use in metallurgical and other industrial furnaces, there is a wide range of coals available, although the choice of any especial kind of furnace may be limited. In other words, a coal that may be adapted for use in one type of furnace may not suit at all for another.

For metallurgical furnaces, as distinct from blast furnaces and foundries, a medium or high volatile coal, low in sulphur and with high ash-fusing point is required. Today, however, the use of powdered coal for metallurgical work is rapidly growing, and hand fired or stoker fired furnaces will soon be a thing of the past at all plants of any size. Cement making plants have long used powdered coal exclusively in their kilns.

Analysis will not always show what coals are best

suited to a particular type of furnace and material worked; actual trial is often necessary and indeed, advisable. As a guide to the selection of coal for industrial furnaces, the following general data is given.

Smithing Coals.

A good smithing coal should fill the following requirements:

1. The coal should coke sufficiently to form an arch over the metal.
2. Analysis should be approximately as follows:

Sulphur, not over -----	1.0 per cent
Ash, not over -----	7.0 per cent
Fixed Carbon, not less than---	70.0 per cent
Moisture, not over -----	12.0 per cent

Analysis, however, will not always give the necessary information as to decide whether a coal will give good results in the forge or not.

First-class smithing coals are not very plentiful, although many different coals are used for that purpose.

For years, the Blossburg coal from Tioga County, Penna., and the Georges Creek coal from the Cumberland-Piedmont region in Maryland, were considered the best that could be obtained, but other coals have been found to be quite as satisfactory.

Many of the low volatile, low sulphur coals of West Virginia and Pennsylvania make excellent smithing coals and are widely sold as such; some of the medium volatile (26 to 32 per cent) coking coals of Virginia and West Virginia are also used with good results. There is no better smithing coal than good, clean Pocahontas or New River slack. In fact, many users who buy special blacksmith coal could just as well use the clean slack from their steam coal.

COALS GENERALLY SUITABLE FOR USE IN
INDUSTRIAL FURNACES.

State	District or Seam
Colorado	Las Animas County
	La Plata County
Illinois	No. 2 Seam
	No. 6 Seam
Indiana	Block
	No. 4 Seam
Kansas	Weir-Pittsburgh Seam
Kentucky, E.	Alma Seam, Pike Co.
	Blue Gem and Jellico
	Elkhorn Seams
	Fire Clay
	Pond Creek
	Harlan
	Hazard
	Millers Creek
Maryland	Tyson
	Upper Freeport
	Big Vein
Montana	Carbon County
New Mexico	Cascade County
	Colfax County
	Lincoln County
Ohio	No. 6 Seam
	No. 2 Seam
Oklahoma	Hartshorne Seams
	McAlester-Lehigh
	Pennsylvania
	Blossburg (Smithing)
	"D" Seam (Clearfield Co.)
	"B" Seam (Cambria Co.)

"C" Seam (Somerset Co.)
Pittsburgh
Tennessee, E.----Blue Gem-Jellico
Coal Creek Seam (Caryville District)
Mingo Seam
Sewanee Seam
Dean Seam
Utah-----Carbon County
Virginia-----Banner Seams (Wise Co.)
Darby Seam (Lee Co.)
Imboden Seam (Wise Co.)
Taggart Seam (Wise Co.)
Washington-----King County
Kittitas Co. Roslyn Seam
West Virginia----Alma Seam, Kanawha District
Beckley Seam, New River District
Cedar Grove Seam, Kanawha and
Thacker Districts
Coalburg Seam, Kanawha and Thacker
Districts
Eagle Seam, Kanawha & Thacker Dsts.
Elk Garden District (Smithing)
No. 5 Block Sm., Kanawha (Smithing)
No. 2 Gas Seam, Kanawha (Smithing)
Sewell Seam, New River
Fire Creek Seam, New River
Powellton Seam, Kanawha District
Winifrede Seam, Kanawha District
Pittsburgh Seam, Fairmont Low Sul-
phur District

COAL FOR COKE MAKING.

The primary qualification of a coking coal is naturally, that it must coke, that is, fuse and become a pasty,

porous mass when fired or when heated to a certain temperature, the gases being distilled off during the heating, while the coal changes its structure entirely, from a more or less solid mass to a porous, (a mass of cells) cellular form.

The change in mass and structure is the indication of the difference between a coking and a non-coking coal, as the latter will not fuse or change its structure to a cellular one at any oven temperature.

To make a good metallurgical coke, especially in beehive ovens, the coal must not only coke, but it must change to coke of a structure that will stand the necessary burden in the furnace or cupola and handling and transportation, with sufficient cell space to enable the gases to penetrate the mass; in other words, the cell walls must be strong and tough, yet not too close together.

John Fulton ("Coke," 1905) gave as the most desirable ratio of cell space to cell wall, 44 to 56, and the average for good Connellsville coke as 39.53 to 60.47.

Sulphur and Phosphorus in Coal and Coke.

A good coking coal should contain not to exceed 1.25 per cent of sulphur, preferably less than one per cent and not over .022 phosphorus, preferably less.

The objection to sulphur in coke is that it tends to make the hot iron brittle or "red short," while phosphorus has the effect of making it "cold short" or brittle when cold.

Some of the sulphur in the coal is driven off during the coking process, the amount varying with the shape in which the sulphur is found in the coal, but generally from 60 to 70 per cent is left in the coke. Of the phosphorus in the original coal, practically all remains in the coke.

Volatile Matter in Coal for Beehive Ovens.

For coking in beehive ovens, there is a wide range of

coals available in this country, from Pocahontas, with 17 to 18 per cent volatile matter, to Pittsburgh seam coal with 37 per cent. The famous Connellsburg, Pa., coking coal contains about 30 per cent, the Durham (England) 29 to 32, Wise County, Va. coking coals 33 to 35 per cent, Colorado coking coal, 28 to 29 per cent.

Other coking coals of practically the same volatile content as some of these mentioned will not make satisfactory coke so that it can be assumed, as is the case, that it is not always the amount of volatile matter alone that governs, but also its character and constituents.

Ash In Coking Coal.

A good coking coal should contain not over 7 to 8 per cent ash, although many otherwise good coking coals will contain 10 to 13 per cent.

High ash in the coal is, of course, detrimental in every way, especially since all of the ash in the coal remains in the coke, the percentage of coke obtained from a given coke, or the percentage of coke obtained from a given amount of coal (usually taken as one ton); this yield may vary from 55 to 63 per cent in the beehive oven and from 65 to 75 in the by-product oven. For instance, a coal with 6.42 per cent ash would, at 74 per cent yield, give a coke containing 8.18 per cent.

Coal for By-Product Ovens.

For by-product coking, the coal must be more carefully selected as regards both volatile content and the nature of the latter; the choice being largely dependent upon the product desired, that is, whether a good yield of metallurgical coke is the primary object or whether a large yield of by-products is the more desired. Of course a good yield of the latter is always desired, so that the

low volatile semi-bituminous coals, such as Pocahontas are not suitable for by-product coking, **except** when mixed with high volatile coals, a common practice.

The average volatile content of the by-product coking coal used in this country varies from 26 to 30 per cent, usually obtained by mixing the required percentages of low and high volatile coals, as for instance, 20 per cent Pocahontas and 80 per cent Kanawha coals; many coke plants, however, use 30 per cent volatile mixture and a few as high as 35 per cent. Changes in oven design and operation have, in the last two or three years, widened the range of coal for by-product oven use; quite a number of Illinois coals can be successfully used today and Indiana coal has also been successfully used.

To determine therefore the exact suitability of any coking coals, for a given plant, the conditions of manufacture and products desired must be taken into account.

Coking Tests.

To determine certainly whether any coal will make good coke or not, actual coking tests in the oven are generally considered necessary.

Numerous laboratory tests have been proposed and some are in use today; the most commonly used test, especially in Europe, is the "Campredon," named from its originator; this test gives a "coking index for different coals, such index showing the number of grams of fine white sand which one gram of coal can bind together in a coherent mass. This amount will range from 9 to 15 grams for different coking coals; a coal with an index of 13 is considered a good coking coal.

Determination of the percentage of oxygen will also give definite information regarding the coking quality of coal; the reliability of this index is being more and more recognized.

ANALYSIS OF FOREIGN COKING COALS, as shipped.

		Moisture	Volatile	Fixed Carbon	Ash	Sulphur
Great Britain						
Durham	-----	0.58	25.50	71.57	2.93	0.71
		1.23	23.60	65.90	7.94	1.33
		0.82	24.80	69.87	5.33	0.92
		1.20	24.10	65.12	9.58	0.54
S. Wales	-----	1.68	32.42	60.78	5.12	0.79
		1.48	24.85	64.70	8.97	0.89
		0.76	25.44	69.68	4.12	0.73
Yorkshire	-----	0.78	32.52	60.83	4.97	0.90
		2.11	30.43	59.95	7.00	0.51
Canada						
Cape Breton	-----	Dry	33.7	57.1	9.2	0.6
		Dry	34.3	59.8	5.9	1.8
		Dry	26.3	64.7	9.0	0.5
Crows Nest Pass	-----					
France			18.24	69.78	3.1	.74-82
Germany						
		1.5	26.4	66.2	5.9	0.9
		1.6	27.5	63.3	7.6	1.2
		1.14	23.71	70.04	5.11	0.96

		Moisture	Volatile	Fixed Carbon	Ash	Sulphur
Australia						
New S. Wales	-----	0.80	21.52	65.54	12.14	0.329
		0.93	23.57	67.00	8.50	0.45
India						
Deshergur	-----	1.32	35.11	52.60	10.97	0.55
Africa, South						
		---	31.00	58.00	11.00	0.53
			26.80	64.00	7.40	1.00
		1.89				
Japan						
Meiji	-----	2.28	38.21	48.23	11.28	0.79
China						
Kaiping	-----	0.62	29.49	65.10	4.78	0.68
Ching Hsing	-----	0.59	27.97	63.76	7.68	0.69
Ping Hsing	-----	1.70	30.33	63.34	4.63	0.48

ANALYSES OF U. S. COOKING COALS, AS RECEIVED AT OVENS.

	Moisture	Volatile	Fixed	Ash	Sulphur
Pocahontas, West Va. -----	3.81	18.20	74.85	6.95	0.66
New River, West Va. -----	Dry 4.03	20.39 19.12	73.01 74.58	6.60 6.30	0.75 0.82
E. Kentucky -----	3.23	29.25	63.55	5.78	0.63
	2.50	35.40	56.60	8.00	0.60
	3.29	35.59	59.70	4.71	0.64
	1.50	32.50	61.00	6.00	0.60
Southern West Virginia-----	2.50	34.68	58.08	7.24	0.08
	3.20	28.00	57.00	5.00	0.80
Southwest Virginia -----	2.18	35.15	61.01	3.84	0.55
Fairmont, West Va. -----	2.69	35.42	56.63	7.95	1.36
	---	38.59	53.40	8.01	2.25
Connellsville, Penna. -----	2.00	30.50	59.88	7.62	1.09
	4.36	30.50	60.92	8.58	1.12
	3.48	30.18	58.94	10.88	1.17

	Moisture	Volatile	Fixed Carbon	Ash	Sulphur
Alabama, Pratt, Washed -----	8.22	29.76	64.32	5.92	1.32
Alabama, Blue Creek, Washed-----	7.31	29.58	60.49	9.93	1.29
Youghiogheny, Penna. -----	3.21	33.65	59.59	6.76	1.05
Northern West Va.-----	Dry	21.95	68.87	9.68	1.40
Greensburg, Penna. -----	0.92	30.25	61.50	7.33	1.00
	-----	29.00	58.00	10.00	1.50
Fayette County, Penna. -----	2.90	34.24	57.06	8.70	1.17
Somerset County, Penna. -----	2.96	16.91	74.05	9.04	1.15
Colorado, Trinidad -----	-----	28.92	59.08	12.00	0.49
Indiana County, Penna.-----	5.5	28.00	60.14	6.46	1.28
Washington, Carbonado -----	0.93	33.10	53.50	12.47	0.67

GAS PRODUCERS AND THE FUEL USED IN THEIR OPERATION.

While the use of gas producers is not as wide-spread in this country as it is in European industries, their number is increasing and a large tonnage of coal, both anthracite and bituminous, is consumed as fuel in their operation.

The ordinary type of gas producer has no by-product, gas being the sole commercial product.

By-product gas producers have not yet been introduced into actual use in this country to any extent. The name "by-product" is given them because, in addition to the main product, gas for power, they also produce ammonium sulphate in much large proportions than do the by-product coke ovens, the yield being directly proportionate to the nitrogen content of the coal used as fuel; while in the coke ovens, an appreciable amount of the nitrogen of the coal remains in the coke. A certain amount of tar is also produced, but is of inferior quality and nature as compared with tar from illuminating gas plants and by-product coke ovens.

The greater first cost of the by-product producer makes its use prohibitive except where large amounts of coal are to be gasified.

Producer Gas, How Made.

Producer gas is the product of the joint action of air or usually in modern practice, air and steam, on carbon; the gas, while poor in heating value, is produced in large quantities and can be used either in gas engines for power or as fuel under boilers and in metallurgical furnaces.

Producers, Types of.

Two general types of producers are in use today, the pressure producer, in which the air and steam is forced through the fuel by steam jets or blowers; the suction producer, where the suction stroke of the engine pulls, or sucks, the air and steam through the fuel bed.

The pressure producer is in more general use, especially where gas is required in large quantities for power and heating.

Pressure Producers.

For the pressure producer, bituminous coals are generally used, but anthracite also and in fact almost any kind of coal, no matter how high in ash,—coke, coke braise, peat, lignite, wood and wood waste—almost any carbonaceous material, provided it will not cake in the producer and will not clinker readily. The objections to a caking or coking coal are that it reduces the surface of the burning fuel exposed to the action of the air and steam, also making holes in the fuel bed, hence giving a more or less porous bed.

Suction Producer.

In the smaller suction type, either anthracite coal or coke is more commonly used, especially abroad.

For instance, quite a large tonnage of the Welsh and French anthracite is used for this purpose alone.

The character of ash of the fuel used in any type of producer, is of more importance than its amount, as, if the coal clinkers readily, more steam must be used, which makes the gas poorer; while the clinker also interferes with the action of the blast and adds to the labor of keeping grates free and the producer working.

By-Product Producers.

The "Mond" system of making producer gas, the producer itself being commonly called the "by-product"

producer, makes use of the fact, first shown by Young & Beilby in England, that completely gasifying incandescent coal (or coke) in a current of air and steam, will produce, besides a large amount of combustible gas (as much as 140000 cu. ft. per ton of coal, with a heating value of around 130-140 B.t.u. per cu. ft.) an amount of ammonia equivalent to at least 65 per cent of the amount of nitrogen contained in the coal.

There has been but little development of this process in the United States but two plants having been in operation to date, both using the Lymn-Riley by-product producer, a later system than the Mond, but based on the same first principles.

Just previous to our entering the Great War, one of the largest corporations in the country was actively investigating the possibilities of building a large by-product producer plant, calling for the gasification of nearly a million tons of coal per year. Selections of coals and sites were made, but the war put a stop to the whole matter and it has not been taken up since.

There is little doubt, however, of the eventual more extended use of this process as a means of using low grade fuel, adding to our supplies of fuel gas for power and other purposes as well as giving further supplies of needed fertilizers (a need that will be felt more and more) and other useful ammonia compounds.

PULVERIZED COAL.

The burning of coal in a pulverized or powdered form has reached large proportions, in this country; its use is growing every year, as its advantages become better known and better methods of handling it are devised.

For a long time and indeed by many users of coal to-day, the dangers of handling powdered coal have been

considered as overcoming its advantages as regards combustion efficiency and its ability to make use of comparatively low-grade coals; in addition, the cost of drying and pulverizing has kept many consumers from using powdered coal.

Developments of the last three or four years have added considerably to the possibilities of powdered coal, by reducing costs of operation, by widening the range of available coals and by minimizing the dangers in handling.

Today it is estimated that about 10,000,000 tons of powdered coal are burned annually in this country; about 6,000,000 by cement making plants and 3,500,000 in various kinds of metallurgical furnaces; the amount used under boilers is comparatively small, probably 200-300,000 tons per year, but growing.

The use of pulverized coal on locomotives has been a matter of investigation and experiment for some years, without, as yet, any large development in this country; the Brazilian State Railways have now in use some fifteen or twenty locomotives using powdered coal as fuel and trials are now being made on the Italian State Railways.

Combustion With Powdered Fuel, The Process of.

The fuel, pulverized so that about 85 per cent of it will pass through 200 meshes to the inch, is blown or fed into the furnace or chamber, with a low air pressure, and is mixed with the exact amount of air needed for combustion, the mixture being kept at a high temperature, the final combination of air and coal occurring at the moment of projection into the furnace.

As each particle of fuel enters the heated combustion

zone, the volatile matter is at once distilled off and together with the remaining particles of carbon meets the required amount of oxygen for instantaneous combustion, so that there is no difficulty in maintaining high temperature and even combustion.

The thoroughness and quickness of combustion as compared with the use of coal in ordinary furnaces can be readily understood; if we take a piece of coal 1 cu. in. in size, its exposed surface will total 6 sq. in. while if we take the same piece and pulverize it to the size of $1/100$ of a cu. in. the exposed surface will total 600 sq. in. This being the case, each one of these small particles being surrounded with air, insuring the needed amount of oxygen, with the continued high temperature, much more complete, almost perfect combustion is certain, as compared with that of the 1 inch cube of coal.

Coal for Use In Pulverized Coal Furnaces.

Until lately, it was thought and stated as a fact, that only coal with about 30 per cent volatile matter or over, could be satisfactorily used in pulverized form.

Today, in actual use, almost any form of solid mineral fuel is used, anthracite screenings and culm, lignites, and even coke, although the latter is usually mixed with a certain percentage of bituminous coal; peat is now being used in Sweden on locomotives, mixed with bituminous coal.

Pulverized Coal Under Stationary Boilers.

The use of pulverized coal under boilers presents many advantages, as compared with either stoker or hand firing. The advantages claimed over stoker firing are summarized as follows: (C. F. Herinton, "Powdered Coal as Fuel.")

1. Much wider variation in quality of coal usable—powdered coal use overcome largely troubles due to poor coal.
2. Greater ability to handle peak loads,—more flexibility of operation.
3. The entire firing operation can be stopped by merely throwing a switch.
4. Ash can be more easily handled—no cleaning of fires.
5. No clinkering on grates.
6. Pulverized coal is fired dry, obviating possible moisture losses.
7. Less excess air is required—lower stack losses.
8. No combustible goes out in the ashes.
9. High sulphur coal can be burned more readily.
10. Smokeless operation can be maintained indefinitely.
11. Less troubles with furnace lining—more uniform temperatures.
12. Steam can be raised much more quickly.

Powdered Coal In Metallurgical Furnaces.

The use of powdered coal in metallurgical and other furnaces for copper roasting, smelting and iron and steel manufacture, has already reached large proportions and is well past the experimental stage.

By its use any degree of heat desired in the furnace can be attained and the heat held constant; an especially important requirement in metallurgical work.

Powdered Coal,

Characteristics of As a Fuel.

It is claimed that by pulverizing coal to the degree of fineness required for combustion, we have changed the character of the coal entirely, giving it a much wider degree of flexibility, with a flame length that can be accurately adjusted both as to length and size, perfect

control of its combustion and, in fact, giving it the characteristics of oil or gas, but with closer control possible.

Delivery of Powdered Coal.

One of the later developments in the use of powdered coal is the installation, in at least two cities, of a central pulverizing and drying plant, from which the powdered coal ready for use, is delivered in 5-ton motor trucks to the consumers fuel storage tanks. From these tanks, placed under the sidewalk (in the usual place for coal bins) the fuel is taken by screw conveyors and air blowers and distributed through pipes to each boiler or furnace, the air for combustion being furnished by another low (3 oz.) pressure blower.

BRIQUETTES, COAL.

The manufacture of coal briquettes is probably one of the oldest industries in the world, although its modern development dates back to about 1860.

The first English patent was taken out in 1789 and in France in 1832. In 1869, there were 31 briquette plants in France, 9 in Belgium and an output of 200,000 tons per year in England. The first German plant was built in 1867; for many years, Germany has occupied first place in the briquetting industry.

The origin of briquette making, however, seems to have been traced to China, where a ball-shaped, compressed coal, with a clay binder, was made by hand and used for heating, probably several hundred years ago.

Process, Briquetting.

The more modern development and use of briquettes, or "Patent Fuel," as they are known in Great Britain, was brought about by the need for finding some use for the slack or small coal made in mining and screening out the

large, or lump coal, at a time when the present uses for slack had not been developed.

The process is a simple one, consisting merely in crushing the coal, drying it, mixing with a binder of some kind, heating the mixture and subjecting it to pressure in molds of the desired shape and size.

Binders for Briquettes.

Except in the case of some lignites, a binder is necessary, as merely subjecting the crushed coal to pressure, while it will hold together, makes a product too easily broken, that would not stand handling or weathering.

The binder most commonly used is pitch, made from either wood, petroleum or coal, usually the latter; there are, however, other binders in successful use, and a great many substances have been tried for the purpose, most of them without much success.

In Germany, a large tonnage of briquettes is made from brown coals, or lignites, without the use of any binder, the raw material being subjected to a heavy pressure, usually from two to two and a half tons per square inch, the moisture and "bituminous" constituents acting as a binder.

Briquettes In United States.

In this country, the manufacture of briquettes has not yet reached a stage where it can be considered of much importance, the entire output during 1920 having been only 567,192 net tons, from 15 plants, most of them in the Eastern States, although the largest one is at the head of the lakes.

Of the 15 plants operated in 1920, eight used anthracite, one Arkansas semi-anthracite, one a mixture of semi-anthracite and bituminous slack, one semi-bituminous slack, one a mixture of bituminous coal and sub-bitumin-

ous slack, one lignite and two carbon residue from oil gas manufacture.

Coals Used for Briquetting.

Both anthracite and bituminous coal are successfully used for briquette making, sometimes a mixture of both; coke has also been used, but not as yet with success as a commercial proposition; not however, because it is not suitable as a fuel or that it will not make good briquettes, but on account of machinery difficulties, which will, no doubt, be overcome, have been, in fact.

Sawdust and other refuse material, having sufficient heating value, have also been briquetted successfully; peat makes excellent briquettes after it has been dried.

Size and Shape, Briquettes.

Briquettes are made in various shapes and sizes, from the small oval or egg shaped ones, weighing one or two ounces (called "Boulets" or "eglettes") to rectangular, brick shapes ones, usually with rounded edges or corners, weighing from 8 to 22 lbs.; the smaller sizes being mostly used for domestic heating purposes and the larger for steam making, especially on locomotives.

Heating Value of Briquettes.

The heating value of coal briquettes is usually rather higher than that of the coal from which they were made, especially where pitch is used as a binder and their analysis will be practically the same as that of the coal, but with slightly higher volatile content.

Storage of Briquettes.

One great advantage of pressed fuel is the ease with which it can be stored for any length of time and under any condition, without deterioration, either in size or

heating value, together with entire freedom from liability to spontaneous combustion.

Combustion of Briquettes.

In actual use, briquettes will give better results as regards consumption and evaporation or steam making than can be obtained from the coal of which they are made, this being due not so much to their greater heating value as to the more uniform distillation of gases and the more even distribution of air through the fire, on account of the uniformity of shape and size, the latter condition making them also easier to fire and requiring less slicing and levelling of fires.

For the same reasons, the production of smoke is less than with the raw coal.

It is also an observed fact, attested to by many users, that briquettes will not make as many clinkers as the raw coal will under similar combustion conditions.

The writer remembers distinctly an experience of crawling into the furnace of a marine boiler, after a long test of briquettes and allowing the fires to cool and burn down to ash without disturbing them, in order to find the exact condition of the remaining refuse; the result being that no clinkers could be found of any size larger than a walnut, although the coal from which the briquettes were made would undoubtedly, in the ordinary way, have made a lot of good sized clinkers, that could have been found without going into the furnace. This experience having been previous to the use of the ash-fusion temperature determination, no test of that kind was made, nor is it probable that it would have shown any difference between the ash fusion temperature of the briquettes and that of the raw coal.

The comparative freedom from clinkers may possibly

be due to the crushing and thorough mixing of the particles of coal and its ash, distributing the ash uniformly through the briquette, giving no nucleus for clinker formation; also to the fact that the fires with briquettes seldom or never have to be sliced or disturbed, thus keeping the ash from being brought into the hottest zone of the fire.

CHAPTER VI.

ANTHRACITE COAL.

With a few comparatively unimportant exceptions, the anthracite coals of the United States are all found in Eastern Pennsylvania, the entire field having an area of about 427 square miles.

REGIONS.

Pennsylvania Region.

The anthracite region is divided into four fields, according to locations, as follows:

Northern-----	Wyoming and Lehigh
Eastern Middle -----	Lehigh and Schuylkill
Western Middle-----	Schuylkill and Lehigh
Southern-----	Schuylkill

There is a further sub-division, made by the State, into seventeen mining districts, also according to location.

Other Regions.

Small deposits of anthracite are found in Rhode Island, Colorado, New Mexico and West Virginia, and of semi-anthracite in Virginia and Arkansas, and Pennsylvania.

Use, Historical.

The first known use of anthracite was in 1770 or 1771; it was called "stone" coal and served locally as a blacksmith forge coal.

Anthracite coal has been mined in this country since

1775, but the first actual shipping records, date back to 1820, when 365 tons were shipped. The first known shipment was sent down the Susquehanna river from Wilkes-Barre to Harrisburg, thence to the Government arsenal at Carlisle. Last year, 1920, shipments amounted to 68,915,460 gross tons, production 79,550,000 gross tons.

Preparation.

As is well-known, all anthracite coal today is screened and prepared in different sizes, descriptions of which, with analyses, will be found in the table following.

Of the total shipments, about 60 to 65 per cent is made up of the so-called "domestic" sizes.

Broken

Egg

Stove

Nut

Pea (also classed as a steam size.)

The steam sizes making up the remaining 35 to 40 per cent are:

No. 1 Buckwheat

No. 2 Buckwheat (Rice)

No. 3 Buckwheat (Barley)

No. 4 Buckwheat

Birdseye, a mixture of No. 1 and No. 2 Buckwheat.

Use, Different Sizes.

The uses to which the different sizes are put are, in general, as follows:

Lump	-----	Locomotive fuel
Broken	-----	Domestic furnace and forges
Egg	-----	Domestic furnaces and ranges
Stove	-----	Domestic furnaces and ranges
Nut	-----	Domestic furnaces and ranges
Pea	-----	Domestic furnaces and ranges
Pea	-----	Boiler fuel
No. 1, No. 2, No. 3 and		
No. 4 Buckwheat	-----	Boiler fuel

COMPARISON BETWEEN WELSH AND PENNSYLVANIA ANTHRACITE.

Sizes and Analyses.

Pennsylvania Anthracite, Sizes of:

	Over	Through
Broken -----	$3\frac{1}{4}$ "	$4\frac{1}{2}$ "
Egg -----	$2\frac{1}{4}$ "	$3\frac{1}{4}$ "
Stove -----	$1\frac{1}{2}$ "	$2\frac{1}{4}$ "
Nut -----	$\frac{3}{4}$ "	$\frac{3}{4}$ "
Pea -----	$\frac{1}{2}$ "	$\frac{1}{2}$ "
Buckwheat No. 1 -----	$\frac{1}{4}$ "	$\frac{1}{4}$ "
Buckwheat No. 2 (Rice) -----	$3/16$ "	$3/16$ "
Buckwheat No. 3 (Barley) -----	$1/16$ "	

All screenings through circular perforations.

Welsh Anthracite, Sizes of:

Machine Made Cobbles -----	$2\frac{1}{4}$ "	$3\frac{1}{2}$ " or 4"
Screened Cobbles -----	$1\frac{1}{4}$ "	3 "
Stove Nuts -----	$\frac{3}{4}$ "	2 "
Paris Nuts -----	$\frac{3}{4}$ "	$2\frac{1}{4}$ "
French Nuts -----	$1\frac{3}{4}$ "	$2\frac{1}{4}$ "
Pea Nuts -----	$\frac{1}{2}$ "	$1\frac{1}{4}$ "
Beans -----	$\frac{1}{2}$ "	1 "
Peas -----	$\frac{1}{4}$ "	$\frac{5}{8}$ "
Grains -----	$\frac{1}{8}$ "	$\frac{1}{4}$ "

Rubbly Culm.

All coal up to $1\frac{1}{4}$ " from first screening.

Duff, Breaker.

Small and dust left after extraction of large cobbles, nuts, beans and peas from the broken large.

Duff, Billy.

Fine small coal left after extraction of cobbles, nuts, peas and beans from rubbly culm.

All screenings through longitudinal bars.

ANTHRACITE COALS.

Corresponding Sizes of Welsh and Pennsylvania Coals.

British	Pennsylvania
Machine Cobbles	Egg
Screened Cobbles	Stove
Stove Nuts	Nut
Paris Nuts	Stove and Nut
French Nuts	Stove
Pea Nuts	Pea and Nut
Beans	Pea
Peas	No. 1 Buckwheat
Grains	No. 2 Buckwheat
Rubbly Culm	No corresponding size, a mixture of pea and 1, 2, and 3 Buckwheat nearest.
Duff	No corresponding size, a mixture of Buckwheat sizes.

ANALYSES OF PENNSYLVANIA ANTRACITE COALS

As sampled by the U. S. Bureau of Mines.

	Moisture	B.t.u.	As Rec'd	Dry	No. of Analyses
		B.t.u.		Ash	
Broken -----	3.87 %	12782	13928	11.11 %	18
Egg -----	4.60	12658	13268	11.30	4
Stove -----	3.81	12585	13084	12.05	19
Nut -----	4.80	12365	12988	12.48	6
Pea -----	3.85	12150	12637	15.25	119
No. 1 -----	4.66	11449	12009	18.54	49
No. 2 -----	7.56	11365	12295	16.77	18

RANGE OF ANALYSES, PENNSYLVANIA ANTHRACITE COALS, as shipped

	Ash Per Ct.	Fixed Carbon Per Ct.	Volatile Matter Per Ct.	Moisture Per Ct.	Sulphur Per Ct.
Broken -----	7-10	81-84	4 to 6	1 to 2	0.7
Egg -----	8-11	80-83	4 to 6	1 to 2	0.7
Stove -----	9-12	79-81	4 to 6	1 to 2	0.7
Nut -----	10-13	77-80	4 to 6	3 to 4	0.7
Pea -----	13-15	76-78	4 to 6	3 to 4	0.7
Buckwheat No. 1	16-20	71-75	4 to 6	3 to 4	0.7
Buckwheat No. 2	18-22	69-73	4 to 6	3 to 4	0.7
Buckwheat No. 3	20-25	66-71	4 to 6	4 to 6	0.7

South Wales Anthracite.

In Great Britain, the anthracite deposits are mainly in South Wales (with a small area in Scotland) in a comparatively restricted area covering about 133 square miles, the maximum output, in 1913, having been 5,194,620 gross tons.

The Welsh anthracite is purer, softer and contains slightly more volatile matter than the Pennsylvania anthracite. It is also screened into the sizes given in the foregoing tables, but its use for domestic purposes is quite limited in Great Britain, where it is mainly used as a fuel for gas producers, malting and other processes, where a smokeless fuel is required, also, to a small extent, for steam making; one half the normal (1913) production was exported (2,147,853 tons), principally to France and Italy.

In composition the Welsh anthracites vary from 6 to 9 per cent in volatile matter, from 4 to 7 per cent ash and from 0.7 to 1.25 per cent sulphur with from 14800 to 14300 B.t.u.

France and Germany contain small deposits of anthracite, while the Russian fields are large and largely undeveloped.

China, Anthracite In.

China is known to contain large deposits of anthracite, of excellent quality and as yet undeveloped to any extent.

CHAPTER VII.

COKE.

Coke is the solid residue left after the destructive distillation of coal or of some other carbonaceous substances. It is a carbonization product of coal, the result of either burning coal with restricted air supply or of subjecting the coal to high temperatures in closed retorts with no air admission.

Coke consists mainly of the carbon and ash of the coal from which it was made, with small amounts of volatile matter, generally less than one per cent, in a good coke, which the temperature of the coking process failed to drive off during the period of coking.

Coke, Classification of.

Coke is usually classified according to its method of manufacture, into

Beehive coke, made in beehive ovens,

By-product coke, made in by-product ovens.

According to the purpose for which it is used coke is classed as

Furnace coke.

Foundry coke.

Domestic coke.

If made in beehive ovens coke is also classed as 48-hour coke (for blast furnaces) and 72 or 96 hour coke (for foundry use), the number of hours referring to the time consumed in carbonization.

Coke for domestic use may be either foundry or furnace, crushed and screened into various sizes, such as egg, stove, nut, etc.

BEEHIVE COKE—The Oven.

This is the simplest type of oven; it consists merely of a round chamber, with a dome-shaped roof, exactly resembling in shape the ordinary beehive, built of stone and lined with firebrick, the ovens being usually built in long rows or "blocks" and the space between each oven filled with earth and stone. Each oven has a door in front, through which the coke is pulled out and a round hole in the top, through which the coal is discharged into the oven.

Beehive Oven Coke.

Coking Process, Description of.

The coal, screened and crushed to about $\frac{1}{8}$ " size, is fed into the ovens through the hole in the top, is ignited and burns for 48 to 72 hours, after which the incandescent mass is drawn out through the door in the side of the oven, is sprayed with water and then loaded into cars for transportation, after which a fresh charge of coal is fed into the oven.

After charging the oven with coal, a cover is put over the hole in the top, while the side door is bricked up to within a few inches of its top, limiting the air supply to the burning coal, so that the volatile matter as driven off burns over the charge of coal.

From 55 to 62 per cent by weight of coke is obtained from the weight of coal charged, depending upon the kind of coal used and the care and skill of the oven boss. This means that from every net ton of coal from 900 to 960 lbs. of coal is consumed in the process, coke being the sole product obtained.

The manufacture of coke in beehive ovens, in this country and elsewhere, has been one of the most wasteful processes known, not only in the actual loss of the coal

consumed, but also in the loss of the valuable by-products and their derivatives, so important and necessary to modern life.

Fortunately, the use of beehive ovens is gradually decreasing and their complete disappearance will depend only on the life of the ovens now in use, as it is highly improbable that any but by-product ovens will be built in the future.

The gradual decrease in production of beehive coke and the corresponding increase in by-product coke production is shown below.

**PRODUCTION OF COKE, net tons
in
UNITED STATES**

	Total Beehive	Per Cent of:		Per Cent of:	
		Total	By- Product	Total	Total
1913-----	33,584,830	72	12,714,700	28	46,299,030
1914-----	32,385,971	74	11,219,943	26	48,555,914
1915-----	27,508,255	66	14,072,895	34	41,581,150
1916-----	35,464,680	65	19,069,361	35	54,584,041
1917-----	33,167,548	60	22,439,080	40	55,606,628
1918-----	30,480,792	54	25,997,580	46	56,478,372
1919-----	19,650,000	44	25,148,542	56	44,793,542
1920-----	20,980,000	40	30,908,000	60	51,888,000

**COMPARISON OF FUEL USED IN BEEHIVE AND
BY-PRODUCT OVENS**

Coking one ton of good coal consumed in beehive oven.	B.t.u.	Equivalent lbs. coal
Gas----- 11,000 cu. ft.	6,160,000	440
Tar----- 9 gals.	1,401,000	100
Light Oils----- 4 gals.	527,000	38
Coke----- 100 lbs.	1,301,000	93
 Total-----	9,388,000	 671
Consumed in by-product oven		
Gas ----- 4,300 cu. ft.	2,408,000	172

For each pound of coal coked, the beehive oven consumes 9,388,000 b.t.u. or about 33.5 per cent of the heating value of the coal, while the by-product oven requires only 3,408,000 b.t.u. or 8.6 per cent.

(F. W. Sperr, Jr. and E. H. Bird, American Chemical Society, Sept. 1920.)

The wastefulness of the beehive oven is well-shown by the preceding figures of fuel loss, but there is another waste in the beehive oven coking process namely, the entire loss of the gas and by-product, as well as that of the lower coke yield.

Losses in coal and by-products due to beehive oven process.

Per net ton of coal.

Beehive Oven Products	By-Product Oven Products.
Coke 1300 lbs.	1400 lbs.
Tar—None	7 to 12 gallons.
Light Oil	1½ to 3 gallons.
Gas—None	9500-10500 cu. ft.

Many attempts have been made to recover the by-products from beehive ovens, but none have met with much success, although at some plants, most of them in European countries, the hot waste gases from the beehive ovens are carried under boilers and used to make steam.

Non-recovery retort ovens have also been and are used to a small extent. In these ovens, coal is heated in long, narrow closed retorts, without admission of air, the gas from the coal being utilized for heating the retorts and also to generate steam. But here, as in the beehive oven, coke is the sole product.

By-Product Coke.

The manufacture of by-product coke, so-called because the gaseous products of carbonization are not wasted as in beehive oven coking, but are carried off during the coking process and made use of, was first started in this country in 1892. The first ovens were of the Semet-Solvay type and were erected at Syracuse, New York.

The Oven.

The by-product oven is a closed retort, from 35 to 50 feet long, 10 to 12 feet high and 16 to 20 inches wide. The retort or coking chamber is heated externally by gas with which pipes or mains are connected to carry off the volatile matters as they are given off from the coal in the retort. There are several different types of by-product ovens in use, in this country, the two most in use being the Semet-Solvay and the Koppers.

By-Product Coke.

The Coking Process.

After the coal is received at the plant, the coal is first crushed to $1\frac{1}{4}$ " size, then elevated to mixing bins, thence to a proportional feeder, the latter for the purpose of getting the required percentages of the different coals used. The mixture is then taken to a pulveriser which grinds the coal to a size of $\frac{1}{8}$ inch, and thence taken usually to storage bins over the ovens from whence it is taken in a charging car and dumped into the ovens through holes in the top and levelled off, after which the charging doors and covers are closed. The usual charge in a modern oven is from 12 to 16 tons of coal and the coking process lasts from 12 to 20 hours, depending upon the quality or kind of coal, kind of coke desired and the type of oven.

During the process the gas is distilled off, the "rich"

gas during the first half of the coking period and the "lean" gas in the latter half. The two qualities of gas are separately collected, and the lean gas is generally used for heating the ovens.

After the gas has been collected, it is treated in several ways to remove the tar, ammonia, benzol, etc. After the tar and ammonia have been recovered, the gas is then distributed for commercial use, although for house use it must first be treated to remove the sulphur.

After the coking period is over, the doors at each end of the oven are removed and a ram, operated electrically, the head of which has the same cross-section as the oven, enters the oven at one end and pushes the coke out of the other end, on to the coke wharf, where it is immediately quenched with water in order to keep it from burning and thus losing heating value.

Yield of Coke and By-Products.

At a modern type plant the yields will be about as follows:

One net ton of coal will yield—

Coke, 75.....	1400- 1500 lbs.
Gas.....	10000-10000 cu. ft.
Tar.....	7- 9 gallons.
Light Oil.....	2- 4 gallons.
Ammonium Sulphate.....	22- 25 lbs.

Uses of Coke.

The principal uses of coke are:

1. In blast furnaces, foundries and metallurgical furnaces as a fuel for melting the charge of ore or metal. This is by far the most important use; in 1918, of a total production of 56,478,000 tons, about 88 per cent was used at blast furnaces alone.

2. In the manufacture of water gas.
3. In certain high temperature and chemical manufacturing processes.
4. As a steam boiler fuel.**
5. As a gas producer fuel.

**Here there is room for much wider use of coke and a logical one. There is no doubt but that coke can be used in many places where its use would mean economy, cleanliness and fuel conservation. All that is needed is suitable handling and furnace equipment.

In Great Britain, urged on by the scarcity of coal during and since the war, coke is used to a much greater extent as a boiler fuel than in this country and with good results.

The possibilities of "blending" coke and coal so as to give smokeless combustion and greater fuel efficiency have been worked out to actual commercial accomplishment, not only with hand firing but also with automatic stokers, using the "Sandwich" system coals or coal and coke, the invention of Mr. E. W. D. Nichol, lately adopted by the London Gaslight & Coke Co. and the Metropolitan Gas Co. for use with mechanical stokers.

The mixture of different kinds of coal in the by-product coke oven, so common a practice here, is a somewhat parallel method and for the same general purpose, greater all around efficiency; both methods are along logical, scientific and useful lines, leading to higher development and accomplishments.

6. As a domestic heating fuel, for which purpose its use is rapidly growing, as its good qualities become better known.

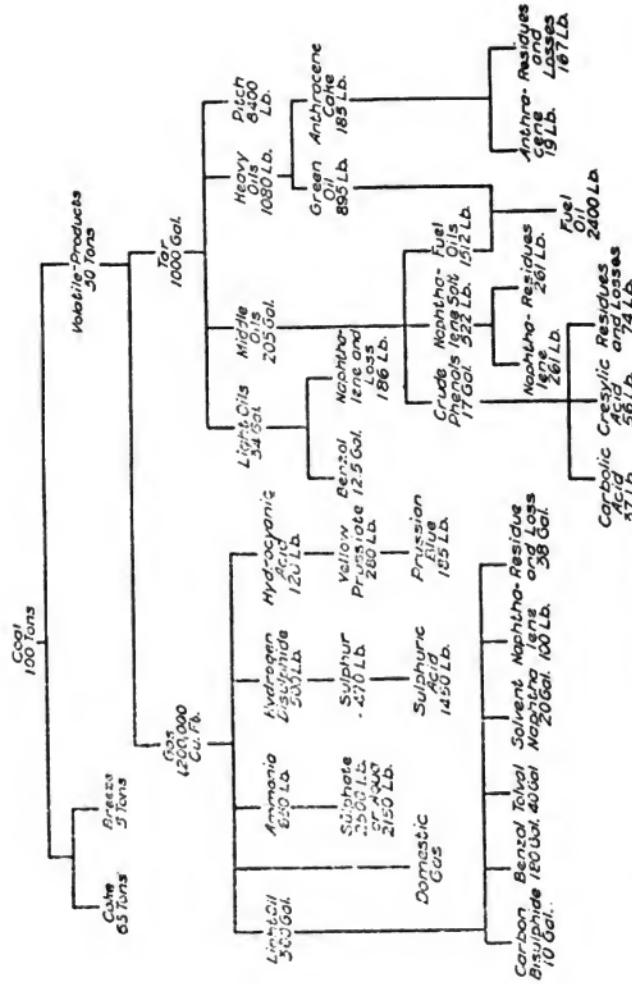
When properly handled, it is a better domestic fuel than either anthracite or bituminous coal, as it is clean, absolutely smokeless and gives out an intense, radiant heat.

By-Products of Coal Carbonization.

By-products obtained from coal, when carbonized in by-product ovens, are the basis of many important industries and make up an entire division of chemistry.

The number and importance of the various substances obtained are growing almost daily.

The following chart, taken from an article in the General Electric Review, July, 1918, by Mr. E. B. Elliott, very clearly illustrates the principal by-products, their derivatives and their relative yields, resulting from the carbonization of 100 tons of coal in the manufacture of coke.



By-Product Coal Carbonization.

The chart just given shows only the principal by-products; from these are obtained by various chemical processes, thousands of other substances, many of them of commercial value, together with some for which little or no use has yet been found; the whole group of products, together with the other carbon compounds, about 150,000 in all, making an entire main division of chemistry, known as "Organic Chemistry" or the "Chemistry of the Carbon Compounds."

In 1918, the sales value of the principal by-products obtained from coke ovens in the United States, amounted to \$74,602,458.00; this amount, however, is only a fraction of the value of products in the manufacture of which coal by-products are an essential part, such value having been estimated at three billion dollars, in this country alone.

Alcohol From Coal.

The recovery of alcohol from coke oven gas has recently (1919) been accomplished in England; if it turns out to be a commercial success, another valuable by-product will be added to those already obtained from coal carbonization.

Low Temperature Carbonization.

Bituminous coals and lignites, when suitably carbonized at a temperature of 850 to 900 degrees Fahrenheit, considerably below the temperature used in gas and coke making, undergo marked chemical and physical changes, whereby their smoke-producing constituents are expelled as hydrocarbon vapors and gases, leaving a somewhat porous semi-carbonized residue containing about 10 to 12 per cent volatile matter. This residue ignites readily and burns freely, without smoke and with a short flame.

This process, known as "Low Temperature Carbonization," offers great possibilities in the way of fuel con-

servation, smokeless combustion and large additions to our supplies of coal by-products.

While the process is not a new discovery by any means (the first British patent (Parkers) is dated January, 1890), actual commercial development is yet in its infancy in this country, and there is today but one plant of commercial size and running on a commercial basis, the fuel output of which has found a ready sale as a domestic fuel; for this purpose it is eminently suited, the coke residue in this particular development being briquetted and the briquettes subjected to a second heating, which brings their volatile content down to 2 to 3 per cent.

Other developments in low temperature distillation are now at an active stage, both in this country and in England; it is undoubtedly a most promising and logical step toward the more economical use of coal.

It might be added, as stated by Sir Arthur Duckham, that too much has been expected of low temperature carbonization; that its advantages are too obvious, making it too easy to draft glowing prospectuses, etc. Some of its own advocates and promoters have been its worst enemies.

In both Germany and France low temperature carbonization has been under close investigation for some years; in the former country it has reached commercial success as far as by-products are concerned, at least.

As showing the chemical changes undergone by the coal in the process the following analyses are given of the raw coal, the semi-coke, or coke residue and the finished briquette, to which the trade-mark name of "Carbocoal" has been given.

	Raw Coal	Coke Residue	Briquette
Moisture -----	1.23	2.21	0.67
Volatile -----	34.07	9.89	2.79
Fixed Carbon -----	59.15	80.12	88.00
Ash -----	5.55	7.78	8.54
Sulphur -----	1.91	1.47	1.42
B. t. u. -----	14401	13382	13168

2000 lbs. of raw coal yield about 1400 lbs. of briquettes.

CHAPTER VIII.

STEAM BOILERS AND FURNACES

The furnace or firebox of a steam boiler is an entirely separate apparatus from the boiler and performs a different function. The furnace is a chamber in which the coal or other fuel is burned; the boiler transfers the heat evolved in the furnace to the water in the boiler. The combustion chamber is really a part of the firebox; it serves as a space in which the combustion of the gases from the burning coal in the furnace is carried on beyond the furnace proper, combustion in the latter being incomplete.

Boilers.

Steam boilers are classed in two main groups.

1. Fire tube boilers, in which water is contained in the main body of the boiler around the tube, heat from the furnace passing through the tubes.
2. Water-tube boilers, in which water is contained in the tubes and headers, heat from the furnace coming into contact with the outside of the tubes.

Fire-Tube Boilers.

In this country, the most common type of fire-tube boilers is the ordinary cylindrical return tubular boiler,

either horizontal or vertical, with furnace and combustion chamber, the latter built of brick and not a part of the boiler itself but usually under it.

The locomotive boiler, while of the same general type, has a furnace or firebox as it is generally called which is a part of the boiler, water circulating between the outside and inside sheets of the firebox (where it is exposed to the heat of the fire) as well as around the tubes; gases from the fire going through the tubes directly to the stack.

Water-Tube Boilers.

There are numerous designs of water tube boilers, such as the Babcock & Wilcox, Stirling, Heine, Wickes, Yarrow, Thorneycroft, Niclausse, and numerous others, each of different design, detailed descriptions of which may be found in the various publications listed in the bibliography.

Each type has its own advantages and disadvantages; the firetube boiler is cheaper to install, but cannot be built in as large units, nor can it be constructed to carry as high steam pressure as the water-tube type. The latter-type is generally considered to be safer as regards explosions, and will make steam more quickly.

SUGGESTIONS FOR HAND FIRING OF BOILER FURNACES.

1. Fire evenly and regularly, putting on approximately the same amounts of coal at each firing, with the same length of interval between firings.

2. Keep fires in such condition that moderate amounts of coal (two to five shovelsful) will be sufficient at each firing and place the coal only where needed.

3. Keep the fires clean and bright all over, except when using the coking methods, when the fresh charge is banked at the door and the fire kept bright back of the bank.

4. Break up large lumps to the size of a man's fist and have the coal as uniform in size as possible.
5. Regulate the draft and air supply to suit the working conditions.
6. Keep the fire free from holes, especially along the sides and back of furnace.
7. Watch closely the conditions of the fire and the steam pressure together and as dependent on each other. If the pressure varies, some change in the fire caused the variation, draft, etc. being the same.
8. Keep the steam pressure even and without variation.
9. Carry water in the boiler at a uniform and regular height.
10. Do not level or stir fire unless absolutely necessary.
11. Find the thickness of fire necessary to prevent smoke and keep up steam and do not allow to vary.
12. Keep flues and heating surfaces clean.
13. Do not allow leakage of air the into furnace or combustion chamber.
14. Do not allow ashes or clinkers to accumulate on walls or in combustion chamber.
15. Clean fires when necessary, but do not allow them to run too long; deficiency of air through grates means incomplete combustion, loss of efficiency and smoke.
16. If the furnace has more than one door or there is more than one furnace to be handled, fire in alternate doors and it is better to put coal on alternate parts of the fire reached by each door. The latter is the so-called "ribbon" method of firing, the coal being put on alternate strips across the full length of the grate, as shown below, A, B, C and D representing that portion of the grates served by one door and 1, 2 and 3, the firing strips across the grates.

A	B	C	D
1	1	1	1
2	2	2	2
3	3	3	3

Fire across A1, A3; B2; C1, C3; D2; then back, D1, D3; C2; B1; B3, A2.

This method gives more even temperature in the furnace, affords a better chance of mixing the gases from the fresh coal with the incandescent gases and heated air from the bright fire, thus preventing smoke, giving a more even steam pressure, systematic stoking and less contraction and expansion of the boiler plates and flues.

18. A regular systematic scheme of firing should be worked out and strictly adhered to under all customary working of boilers. Efficiency can be obtained only through an intelligent and effective system.

19. With all coking coals it will be found necessary to occasionally break up the top of the fire, to fill up holes and level down banks. This should be done with a two pronged hook, with which the top should be levelled, especial care being taken to push sufficient fire to the back of the grates and to not dig too deep into the fire and make holes in it.

20. The levelling should be done between the times at which coal is put on, but sufficient time should be allowed after levelling and before a stoking, to have the green coal broken up by levelling, give off its gases and be in a proper condition to quickly ignite fresh coal to be put on.

21. Firemen should not be permitted to use the slice bar unless the fires get into very bad condition before the regular cleaning time; the period between cleanings should be such as to make its use unnecessary at any other time and for the purpose only of removing clinkers and working ashes through grates. If it is found necessary to break up the fire bed from below the slice bar should be run along the grates and raised only a few inches, so as to avoid bringing the green coal on the grates and the ash bed into the hottest part of the fire. The use of a light T bar, made of pipe, is also recommended for keeping the air spaces open. This bar can be run under the fire and along the grates and will not mix the ash with the hot fire.

The frequent use of the slice bar increases the work of the stokers, makes the fire dirty and wastes fuel through the grates every time it is used.

22. The formation of clinkers can be largely prevented by, first building up the fires slowly to their proper thickness before getting under way; second, by uniform stoking; third, by breaking up and levelling fires from the top and not using the slice bar, thus allowing the ash of the coal to work down of its own weight to the grates and to stay there.

Clinker is fused or melted ash, and the hotter the ash becomes the more quickly it will fuse, so that it is most important to keep it at the coolest part of the fire which is next to the grates.

23. The burning of the refuse from the ash-pit will not be necessary with properly designed grates and good stoking; as there will be so little partly burned coal falling through the grates that any advantage that may be gained from burning it will be more than offset by the added amount of ash and clinkers.

Mechanical Stokers.

There are three main classes of Mechanical Stokers.

(1) **Chain grate** or **traveling grate** stokers, where the coal is fed from the the hopper onto a continuous, jointed moving "grate," which passes over rollers and returns underneath. The coal is ignited after it leaves the hopper, where distillation of the gas begins and combustion continues, as the grate travels on to the back.

This type of stoker is adapted for burning high volatile low-grade, non-coking or feebly coking coals; it also gives excellent results with the small sizes of anthracite. At least one type of chain grate stokers has been designed for coking coals.

(2) **Overfed** stokers have fixed grates, except that every alternate bar is given a slight rocking motion, and the grates are sloping, either from front (top) to back (bottom) or from each side down to the middle. The rocking motion of the grates keeps the coal in motion down the grates to the ash pit, combustion proceeding in the travel of the coal from top to bottom of grates.

All kinds of coal may be used with this type of stoker, although it is not so well adapted for coking coals.

(3) **Underfeed** stokers, so-called because the coal is fed from underneath and pushed up as combustion proceeds, on and over the grates. Coking begins before the coal reaches the grates and the distillation of gases (with admission of air) proceeds until the upper layer or zone is reached, after which the incandescent coke descends and is consumed, the ashes and clinkers being forced on the dumping plate. Stokers of this type will handle a great variety of coals and are much used at the larger plants. They are capable of very heavy duty and will drive boilers to high capacities.

There are of course, many different designs of stoker in each general class; the following list gives but a few representative ones.

Type (1) **Chain Grate.**

Illinois Chain Grate Stoker.

Babcock & Wilcox Chain Grate Stoker.

Coxe Traveling Grate.

Green Chain Grate, Type "K" and Type "L"

Type (2) **Overfeed.**

Detroit Stoker.

Murphy Stoker.

Wetzel Stoker.

Lehigh Stoker.

Type (3) **Underfeed.**

Taylor (Gravity Underfeed).

Jones.

Westinghouse-Underfeed. (Gravity Underfeed).

Riley (Gravity Underfeed).

Type "E" stoker.

Combustion of Coal.

The question of combustion is such a large one, besides being outside of the intended scope of the Manual,

that no attempt will be made to give more than a definition of what it is, with a brief outline of the chemical changes that take place in the combustion of coal.

The importance of the subject and the many questions and problems involved justify an entirely separate "Manual of Combustion," which is now in course of preparation.

Those interested in the subject are referred for information and discussion in detail to the various books and pamphlets listed in the Bibliography, especially the various Bulletins and papers issued by the U. S. Geological Survey and Bureau of Mines on the subject of combustion.

Combustion Process.

In nearly all furnaces, whether under boilers or for metallurgical heating and other processes, combustion of coal takes place in two stages.

1. Combustion in the fuel bed.
2. Combustion above the fuel bed, in the furnace and in the combustion chamber.

In the first stage, the volatile matter is given off and part of the fixed carbon is also gasified; in the second stage the gases and other combustible matter given off mix with air and are burned.

Combustion Over the Fuel Bed.

It would be difficult to give a clearer description than the one following of the combustion process as applied to coal, particularly of that part of the process which takes place above the fuel bed. (See Bulletin 135, U. S. Bureau of Mines.)

"Combustion over the fuel bed is a chemical reaction between gaseous oxygen on the one hand and gaseous, liquid and solid combustible, which rises from the fuel bed, on the other hand. The gaseous and liquid com-

bustible results from gasification of fixed carbon on the grate and distillation of volatile matter. The solid combustible consists chiefly of finely divided carbon, known as soot, which is produced by decomposition of volatile matter. Also particles of coal are carried along with the current of gases. To burn these gaseous liquid, and solid combustible materials oxygen must be supplied by admitting air over the fuel bed. The velocity and completeness of combustion are influenced by concentration, mixing, temperature, and time of contact of oxygen and combustible."

Air for combustion is supplied through the grates and openings in the furnace and sometimes from other openings over the fire; the air thus admitted to the furnace supplying the oxygen required for combustion. When a fresh charge of coal is placed on the fire, the coal is rapidly heated and beginning to give forth gaseous and liquid matter (the latter in the form of small globules of tarry matter), at temperature as low as 480°F, this distillation increasing in rate as the temperature of the coal increases until at about 1020°F. the rates begin to decrease until nothing is left of the coal on the grate, but its carbon (and ash) in solid form, which then burns until it has all changed into gases.

The combustion of coal in furnaces is a chemical process in which reaction takes place between the oxygen of the air and the carbon and hydrogen of the coal, with their different combinations. These reactions, taking place between gaseous oxygen on the one hand and gaseous liquid and solid combustibles on the other, are very complicated. (See "Steaming Tests of Coal" Bulletin 23, U. S. Bureau of Mines.)

If the coal is heated slowly, the combustible matters given off as volatile are small in quantity and gaseous

in composition, making their mixture with the oxygen of the air comparatively easy. But if the fire is forced and the rate of heating rapid, the volatiles distilled off are large in quantity and in the amount of tarry vapor they contain.

The gases of combustion carry the heat from the burning coal to the heating surfaces of the boiler, the latter absorb a great part of this heat and the gases pass on and out through the stack at a rate governed by the amount of draft, due to the difference in pressure between that in the stack and that of the outside air, pressure in the stack being the lower.

Smoke.

Smoke may be defined as the visible evidence of incomplete combustion; the absence of smoke, however, must not be considered as an evidence of complete combustion, as will be explained further on.

Smoke is composed of the products of distillation of the coal, during combustion, which are allowed to escape before combustion is complete, either on account of poor firing or unsuitable furnace equipment, whether from improper design or lack of upkeep, resulting in the distillation products not being mixed with the amount of air necessary to ensure their complete combustion.

The formation of smoke is caused primarily by too much air being mixed with the gases from the coal with subsequent cooling of the gasses.

Incomplete combustion with no smoke, occurs when too little air is admitted to the furnace and combustion chamber.

What we ordinarily call smoke, having especially reference to the brown or black vapor visible to the naked eye, is made up of the gases distilled from the coal col-

ored by the small globular particles of tar and free carbon carried off with the gases.

The losses from excess air supply and consequent smoke production are much greater in the invisible gases than in the visible smoke; the loss from the latter alone will rarely exceed 2 per cent, while the total loss from incomplete combustion may run as high as 30 or more per cent.

Black or brown smoke is therefore to be considered more as the visible evidence of incomplete combustion and bad furnace operation or equipment rather than as a loss in itself.

CHAPTER IX.

Storage of Coal.

The whole question of coal storage is being given a great deal of attention at this time and we are learning more about the various details involved, as a result of the investigation of actual storage conditions and from laboratory experiments, which have given much valuable information.

We will not attempt to discuss costs, either of equipment or operation but will give briefly some of the more important information and requirements involved in the storage of coal, with the premise that coal is to be stored.

There are six main items to be considered in the storage of coal.

1. The amount to be stored and time storage is to be started.
2. Location of storage.
3. Method of storage handling and rehandling.
4. Kind and sizes of coal to be stored.
5. Spontaneous combustion and how it can best be avoided or minimized.

6. Methods of inspection of storage piles.

Amount to be Stored

1. The amount to be stored depends of course upon the users needs and many vary from 10 to 12 tons in a house cellar to hundreds of thousands for the largest consumers and a million or more for railroads, the latter at different locations.

Time of Storage

2. The best time to begin storage is generally considered to be between May and October; this more for economic reasons and in order to take advantage of transportation necessities and keep mines in operation during the summer months.

Storage Location

Storage location should be definitely settled and all arrangements made for facilities in advance of storage. The place chosen should be dry and well-drained, should be entirely free from any other material and there should be no hot walls or chimneys or trestles in contact with the coal; a concrete or clay bottom will help rehandling.

Handling Methods

3. The method of handling and rehandling to be used must be chosen to suit conditions. There are many different systems, each of which has its own advantages for some locations and conditions and disadvantages and unsuitability for other location.

The method of piling used must also depend upon conditions, space available, tonnage to be stored, kind and size of coal, etc.

Prof. Stoek, who is probably the best informed authority in this country on coal storage, gives the following conclusions regarding the piling of coal. (University of Illinois, Bulletin No. 21.)

1. Coal should be so piled that any part of the pile can be quickly removed.
2. Coal should be so piled that air may circulate freely through it, carrying off heat or else packed so closely that only a minimum amount of air can enter.
3. Coal should be piled in horizontal layers and not in conical piles, avoiding stratification of lumps and fines.

Coal for Storage, Kind of

4. All coals, even anthracite, have been known to be fired by spontaneous combustion; but some varieties and sizes are much more liable to fire than others.

To begin with, the coal to be stored should be, as far as local conditions will permit, of a kind that is not known to be especially liable to spontaneous combustion. If there is no choice, then storage and pile conditions must be made to suit, as far as possible, the particular kind to be stored.

One precaution should be observed especially—not to store in the same pile, more than one kind of coal, or coal from different beds in the same field.

Size of Coal to be Stored

The size of coal to be stored should be given careful consideration. If possible, the stored coal should be all of uniform size, the larger size the better; in other words, lump coal will store better and be much less liable to spontaneous combustion than either run-of-mine or small coal (slack).

The size of coal to be stored has much to do with the kind and height of pile to be used. Lump or screened coal can be piled much higher, without danger from fire, than run-of-mine.

If run-of-mine coal is used it is sometimes possible to

screen it while being unloaded, storing the lump and using the smaller coal at once. This practice obtains at some large plants where coal is brought by water during certain seasons of the year only.

Spontaneous Combustion

5. After the question of the necessity for coal storage has been decided the amount to be stored and places available are next in order; these decided upon, the most important item remaining is spontaneous combustion and how to avoid it in the coal stored.

Our knowledge regarding spontaneous combustion in coal has progressed but little since the well-known researches of Henri Fayol, the result of which were published in 1879. These researches covered a period of several years and were based on several hundreds of experiments, carried out on a large scale.

His final deductions were quite in line with our present knowledge on the subject; the general conclusions he finally arrived at were as follows:

- (1) The first essential cause of spontaneous combustion of coal is the absorption of oxygen from air by the coal.
- (2) The best conditions for spontaneous heating of coal are: a mixture of fragments and of dust, a high initial temperature, a large quantity of coal and a certain proportion of air.
- (3) The conditions opposing spontaneous combustion of coal are: storing the coal in large pieces, preserving a low temperature, stacking small quantities and ensuring either complete absence of air or very effective ventilation.

Prevention of Spontaneous Combustion

Unfortunately we do not know enough about spontaneous combustion or its cause, to be able to absolutely

prevent it. The most we can do is to take certain precautions to minimize its starting and to prevent its spread.

We do know that spontaneous combustion in coal is a more or less slow oxidation of the coal or absorption by it of the oxygen of the air, the air supply being sufficient to sustain oxidation but not sufficient to carry off the heat so formed.

Up to a certain point, as measured by the temperature of the mass, the process is a slow one and if there is sufficient ventilation to carry off the heat, the temperature remains low; but as the process continues, with insufficient ventilation, the temperature will rise faster and faster until the coal is ignited and burns.

The danger point is usually considered to be about 100°F. although a higher point must be reached before actual firing, about 180°F. (This is not absolute and varies with different coals.)

Liability of Different Coals to Spontaneous Combustion.

There is a marked difference between different coals as regards liability to spontaneous combustion; the reason for this is not yet definitely and certainly known. We can only say that while each kind of bituminous coal has been stored without spontaneous combustion, yet spontaneous combustion has taken place with every kind of coal known (Prof. Stoek, University of Illinois, Bulletin 21.)

We also may say quite conclusively, that coals of uniform size, free from dust and slack, are generally free from liability to spontaneous combustion, and that the greatest danger lies with run-of-mine coal and with screenings or slack; that a mixture of different sizes is more liable to fire than one size.

It is also a matter of general belief, apparently borne out by facts, that coals of different kinds mixed together will fire more readily than when stored separately. The reasons for this have never been satisfactorily explained.

Storage Conditions as Affecting Spontaneous Combustion

Depths and area of piles depend upon space available and method of handling. A number of small piles are better than one large pile, where space is available. The height of the pile will always depend upon conditions and kind of coal.

In this matter the Bureau of Mines recommends a height of not over 15 feet, preferably lower.

In actual practice, however, one must be governed by the necessities of each case; precautions that can be taken where space is ample, are not always possible when storage area is limited.

As regards storage of coal in the open or under roof, all available data and tests seem to indicate that it makes little or no difference whether coal is stored outside or under cover, as far as any deterioration or liability to spontaneous combustion is concerned.

Sulphur and Spontaneous Combustion.

For many years it was believed that sulphur in coal was one of the primary causes of spontaneous combustion. Later investigations have considerably modified this theory; probably the most that can be charged to sulphur is that its effect on spontaneous combustion is secondary, depending somewhat upon the state in which it occurs in coal. Its active effect is due to the fact that the oxidation of sulphur in the form of pyrites (its most common form) produces a small amount of heat, but more important, it also helps to break the larger pieces of coal and thus increase the amount of fine coal and dust.

However, some low sulphur coals are known to be extremely liable to spontaneous combustion and the mere fact that a coal is low in sulphur does not mean that it will stand storage well; the worst fires that the writer has ever seen were in low sulphur coal.

Moisture and Spontaneous Combustion

As regards the effect of moisture on spontaneous combustion, there is also considerable difference of opinion and the results of tests and investigations have not yet cleared up the question.

The greatest weight of evidence seems to incline to the view that, at all ordinary storage temperatures, moisture will have little or no effect in raising the temperature of the coal pile.

Professor Stoek makes, as one of his conclusions, the statement that repeated drying and wetting of coal seems to increase the tendency to spontaneous combustion; that this may be due to the breaking up of the coal occasioned by alternate drying and wetting, even if no chemical action takes place. He concludes, that it is not wise to put wet coal into a pile, nor to store coal on a damp base and that after rain or snow a coal pile should be carefully watched.

The writer's experience has lead him to believe that any effect that moisture may have on firing of coal from spontaneous combustion is a mechanical one, whereby the moist coal packs more closely together and prevents the escape of heat generated; moist or damp coal as distinct from wet coal, having this tendency to the greater degree.

The following rules for storing coal summarize the best practice; they are taken from a paper distributed by the National Board of Underwriters in 1918, prepared by Professor H. H. Stoek and Mr. W. D. Langtry, Presi-

dent of the Commercial Testing Company of Chicago.

1. Pile the coal to be placed in storage as shallow as possible in the available space.
2. When the coal is unloaded, if it should be lump, egg or nut, see that it is not broken by allowing it to drop a great distance and thus form smaller particles, which may be the source of trouble later on.
3. See that the coal, when it is unloaded, is piled flat—in other words, do not allow it to pyramid so that the lumps will segregate from the fine coal and thus form a chimney for the admission of air to the fine coal.
4. Pack the coal tight rather than try to ventilate it; this will prevent the easy admission of air to the inside of the pile.
5. See positively that there does not get into the pile any material such as oil waste, pieces of paper, straw, wood or anything that is of an easily combustible nature.
6. See that the coal is not wet before being placed in storage.
7. See that the coal is not piled over the top of hot pipes, manholes, or against the hot outside walls of furnaces.
8. Remember that if a fire has started in a coal pile, it is bad policy to wet the pile with water unless the fire has gone so far that it is impossible to work, due to the heat and gases being driven off.
9. If a fire has started in a pile, try to get at the source of trouble by taking the coal out and spreading it over the ground, piling it not more than two feet deep if possible; it will naturally cool down providing, of course, it is not blazing, and the coal

coked until it is glowing red; if very hot it should be cooled with water.

Spontaneous Combustion in Ships Bunkers

The firing of coal in steamship bunkers has been known ever since its earliest use as steamship fuel; not only has an immense amount of damage been done to ships from this cause, but many ships have been lost entirely. Notwithstanding the tremendous losses that have been incurred, but few real investigations have been made to discover the causes and prevention.

The principal results of a recent investigation by a department of the British Government have just been published; the following extract has been taken from the preliminary report.

"There appears to be evidence that, where partly empty bunkers are filled with coal, the coal which has been left in the bunker is liable to become overheated and to fire. Nearly all the fires occurred in the bunkers. These are situated near the stokeholds and are exposed to the heat of the stokehold, which would naturally hasten the process of spontaneous combustion. In one case steam was used to extinguish the fire and a succession of explosions occurred. Explosions have occurred when fires have taken place on board ship in which no steam has been used. These have been due to the distillation of coal gas by heat, which, mixing with the proper proportion of air, has exploded on contact with fire.

"In two cases the coal had been in the bunkers some years; the next longest period the coal had been on board was six months. Otherwise, the period of heating until fire actually occurred appears to have been between three weeks and three and a half months. There are exceptional cases, however, one in which the bunkers were coaled after having been swept out, and a fire broke out in one bunker in four days time and in another bunker a few days afterwards; another in which the fire occurred while the vessel was still in Hoboken, the

coaling port; and yet another in which the cargo of gas coal took fire on the short voyage from Newcastle to Southampton.

"Bunkers it is stated, should be tight, to prevent air from passing through the coal and thus providing oxygen, the absorption of which is attended with overheating. Unless the heat of absorption can be carried off as quickly as it is generated, overheating will occur. Coal remaining in bunkers should be moved to where it can be used first. Small coal is more liable to spontaneous combustion than large coal. Water is the best medium for extinguishing coal fires. It might be added that all coal is apparently, liable to spontaneous combustion. When it does occur on board ship, it is probably due to fortitious conditions in regard to the rate and supply of air (oxygen) and the rate of escape of the heat generated. A slight change of the conditions either way may mean the difference between overheating and the absence of it. Hence a ship may carry coal in the bunkers without fires occurring over a long period of years."

The following table gives the description of coal in which fires occurred:

American	22
South African	8
English	21
Canadian	2
Welsh	15
Australian	4
Scotch	2
Asiatic	7
German	1

Note: Where coal from different sources has been in the bunkers when fires have occurred and no mention is made of the coal that actually fired, all the various kinds are included in this list.

Coal Storage Under Water

The only way by which absolute freedom from spontaneous combustion in coal storage can be assured is that of storage under water.

Of late years, a number of under water storage installations have been made, notably those of the U. S. Government at Colon and Panama, where large tonnages are stored under water, as reserve supplies.

Other large under-water coal storage plants are—

Duquesne Light Company, Pittsburgh, Pa.

Standard Oil Company, Whiting, Ind.

Western Electric Company, Hawthorne, Ills.

An exhaustive investigation on spontaneous combustion of coal in mines has recently (1920 and 1921) been undertaken by a Departmental Committee of the British Government, which has so far included the giving of evidence by the leading chemists, as well as by Colliery Managers and practical miners. The evidence already published gives a vast amount of data from all sides and should result in a considerable increase in our useful information on the subject in general.

The following extract from an editorial in "The Colliery Guardian" on the subject of this investigation, is well-worth quoting.

"The success of measures of this kind, indeed, would possibly be still greater if the physical causes of spontaneous combustion were not clearly understood, just as a knowledge of the root causes of diseases may often indicate the best means of prevention, and in any case tends to the simplification of preventative measures. It is not, therefore, necessary to assume that even successful measures for counteracting difficulties of this kind should be looked upon as rendering further investigations unnecessary or undesirable. The main point is that these practical remedies are available at once, while scientific researches are often long and tedious. Let the practical men, therefore, do all they can to fight this evil, pending the time when further knowledge points out a better way—if indeed such is to be found."

CHAPTER X.

BIBLIOGRAPHY

To those who wish to study the subject in greater detail, the following list of standard books is recommended, covering different phases of the coal industry, except mining.

It must be added that much of the more valuable information regarding coal is found in the numerous papers and pamphlets that have been published by various technical societies, periodicals and government departments,—the reader is referred especially to the numerous bulletins and papers issued by the U. S. Geological Survey and Bureau of Mines and by the Canadian Mines Department.

No entirely satisfactory general book on coal, especially from the American standpoint, has yet been published, and there lies a promising field open today for work in bringing out such a book.

It would be, of necessity, largely a compilation, but none the less valuable and serviceable, in fact, perhaps the best method of handling such an important work, would be to have each leading topic written by a specialist in that topic, a method already adopted in well-known publications in other technical fields.

The various bulletins and papers issued by the United States Geological Survey and Bureau of Mines, form today the most valuable and useful group of publications in existence on coal generally and the United States coals in particular. Unfortunately, owing to the way in which they are issued and printed, these publications have a comparatively restricted field and do not reach many to whom their contents would be of great value; many of them are already out of print and unobtainable except at second hand book stores.

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Political and Commercial Geology ----- J. E. Spurr, Editor.
Keystone Catalog, Annual ----- E. N. Zern, Editor.
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Coal Fields of Great Britain ----- Edward Hull.
Coal in Great Britain ----- Walcott Gibson.

Economics of Coal ----- W. S. Jevons, Revised by A. W. Flux.
The Coal Question ----- W. S. Jevons.
The British Coal Trade ----- W. S. Jevons.
Coal, Iron and War ----- Eckel, E. C.
Nationalization of the Mines ----- F. Hodges.
Political and Commercial Geology ----- J. E. Spurr, Editor.
The British Coal Industry ----- Gilbert Stone.

Chemistry of Coal and Coke ----- W. A. Bone.
Coal and Its Scientific Uses ----- J. S. S. Brane.
Fuel—2nd Edition ----- Sommermaier.
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Steam Power Plant Engineering, 5th Ed.—G. F. Gebhardt.
Finding and Stopping Waste in Modern Boiler Rooms, Revised Edition—Cochrane Corporation.
Forney's Catechism of the Locomotive—Revised by G. L. Fowler.
Practical Locomotive Operation -----C. Roberts and R. M. Smith.
Principles of Locomotive Operation -----A. J. Wood.
Fuel Economy on Locomotives -----American Railway Association, Chicago.

This list does not pretend to be complete, and is intended only as a guide to standard and reliable books on the subject.

COAL FIELDS OF THE UNITED STATES
Principal Coal Producing States and Districts in Each.

State	Field	Districts	Trade Names	Coal Production 1920, net tons.
W. Va.	Pocahontas	Pocahontas	Pocahontas	87,500,000
	Pocahontas	Tug River	Pocahontas	
	New River	New River	New River	
	Kanawha	Kanawha	Kanawha	
	Logan	Logan	Logan	
N. W. Va.	Thacker-Kenova	Thacker-Kenova	Thacker-Kenova	
	Coal & Coke	Coal & Coke	Coal & Coke	
	Gauley	Gauley	Gauley	
	Elk Garden-Piedmont	Elk Garden-Piedmont	Elk Garden, Cumberland Piedmont	
	Fairmont	Fairmont	Fairmont	
Central W. Va.	Upper Potomac	Upper Potomac	Upper Potomac	
	Preston Barbour	Preston Barbour	Preston Barbour, Philipi	
	Pittsburgh No. 8	Panhandle	Panhandle, Wheeling	
	Mason	Mason	No. 8	
	S. W. Va.	S. W. Va.	Toms Creek	
Va.			Clinch Valley	
			Clinchfield	
			Interstate	
			Big Stone Gap	
			Pocket	
Ala.	Birmingham	Cahaba	Cahaba	
		Coosa	Coosa	
Tenn.		Warrior River	Warrior River	
		Coal Creek	Coal Creek	
		Jellico	Jellico	
		Brushy Mountain	Brushy Mt.	

COAL FIELDS OF THE UNITED STATES—(Continued)
 Principal Coal Producing States and Districts in Each.

State	Field	Districts	Trade Names	Coal Production 1920, net tons.
Tenn.----	N. Western----- Southern-----	By Counties & Seams— Tracy City----- Walden Ridge----- Bon Air----- Clearfield-----	Clearfield Beech----- Creek, Moshannon----- Johnstown----- South Fork----- Quemahoning-Meyersdale-----	166,456,101
Penna.----	Central Penna.-----	Johnstown----- South Fork----- Quemahoning-Meyersdale----- Snowshoe----- Broad Top----- Blossburg----- Reynoldsburg----- Latrobe----- Greensburg----- Connellsville, Klondyke----- Youngstown----- Westmoreland----- Pittsburgh----- Low Grade Division----- Indiana----- Allegheny River----- Ligonier----- Elkhorn----- Eastern Ky.-----	South Fork----- Reynoldsburg, Shawmut----- Latrobe----- Greensburg----- Connellsville----- Youngstown----- Westmoreland----- Pittsburgh----- Low Grade Division----- Indiana----- Allegheny River----- Ligonier----- Elkhorn, Marrowbone----- Jenkins----- Harlan-----	31,000,000
Ky.-----				

COAL FIELDS OF THE UNITED STATES—(Continued)
Principal Coal Producing States and Districts in Each.

State	Field	Districts	Trade Names	Coal Production 1920, net tons.
Ky.-----		Hazard Pond Creek Tug Fork Western Ky. by counties	Hazard Pond Creek, Pike Co. By Counties Hocking No. 6-----	45,000,000
Ohio-----	Western Ky. Hocking Valley No. 6 Steubenville Wellston Jackson Cambridge Pittsburgh No. 8 Steubenville	Belmont Federal Creek Swan Creek Pomeroy Meigs Creek Massillon Ironton	Pittsburgh No. 8----- By Counties Clinton-----	30,420,000
Indiana-----	Block Bituminous		Brazil Block Sullivan Greene Vigo Knox Longwall, Third Vein Longwall, Third Vein	90,050,000
Illinois-----	Northern Rock Island Wilmette Fulton-Peoria Grape Creek	Longwall Rock Island Wilmette Fulton-Peoria No. 6 Grape Creek	Wilmette Fulton-Peoria No. 6 Grape Creek----- Vermillion, Danville	90,050,000

COAL FIELDS OF THE UNITED STATES—(Continued)
Principal Coal Producing States and Districts in Each.

State	Field	Districts	Trade Names	Coal Production 1920, net tons.
Illinois	Springfield	Springfield	Springfield, Central	
	Virden	Virden	Virden	
	Pana	Pana	Pana	
	Central Illinois	Central Illinois	Central Illinois	
	Centralia			
	Du Quoin	Du Quoin	Du Quoin	
	Williamson & Franklin	Williamson, Franklin	Franklin, etc.	
	Big Muddy	Big Muddy	Big Muddy	
	Saline-Gallatin	Saline	Harrisburg	
	Pittsburgh	Cherokee	Weir-Pittsburgh	
Kansas	Crawford	Crawford	Weir-Pittsburgh	6,700,000
	Leavenworth	Leavenworth	Leavenworth	
	Kansas, Mo.	Osage	Osage	
	Osage	Georges Creek	Georges, Creek, Gardner	4,050,000
	Georges Creek	Upper Potomac	Elk, Tyson, Freeport	
	Castlemans	Castlemans	Thomas, Railroad, Parker	
	Upper Youghiogheny	Upper Youghiogheny	Honeycomb	
	Lower Youghiogheny	Lower Youghiogheny	Various	
	Northern, Cherokee	Henryetta	Henryetta	
	Southern Cherokee	Tulsa	Tulsa, Dawson	
Maryland		McAlister	McAlister, Hartshorne	
		Lehigh	Lehigh, Atoka	
		Wilburton	Wilburton, Latimer	
		Poteau	Poteau, Witteville	
		Howe	Howe	
Okla.				4,200,000

COAL FIELDS OF THE UNITED STATES—(Continued)
Principal Coal Producing States and Districts in Each.

State	Field	Districts	Trade Names	Coal Production 1920, net tons.
Arkansas -	Arkansas -	McCurtain - Russelville - Spadra - Coal-Hill - Paris - Jenny Lind - Huntington - Camden - Thurber - Eastland - Wise - Young - Palo Pinto - San Carlos - Laredo -	McCurtain, Haskell - Semi-anthracite - Spadra, Semi-anthracite Coal Hill, Denning - Paris - Jenny Lind, Bonanza - Sebastian, Huntington - Camden, Ouachita - Thurber - Eastland, Cisco -	2,310,000
North	Central -		San Carlos - Webb County, Laredo, Cannel - Eagle Pass - Maverick Bevier - Lexington, Putnam Adair -	1,800,000
Eagle Pass -	North Eastern -		Eagle Pass - Lexington, Mendota - Bevier - Adair - Novinger - Coal City - Macon - Randolph - Lafayette - Ray - Vernon -	5,750,000
North	Central -		Rich Hill, Weir-Pitts "b."	
Central West -				
South	Western -			

COAL FIELDS OF THE UNITED STATES—(Continued)
Principal Coal Producing States and Districts in Each.

COAL FIELDS OF THE UNITED STATES—(Continued)
Principal Coal Producing States and Districts in Each.

State	Field	Districts	Trade Names	Coal Production 1920, net tons.
New Mexico--		Capitan-- Monero-- Gallup Durango--	White Oaks Rio Arriba McKinley Gallup San Juan Castlegate Wasatch Harmony Carbon	
Utah--	Great Uinta South Western			5,870,000
Iowa--	No well-defined fields given by counties Appanoose & Wayne	Dallas Boone Mahaska Lucas Marion Polk Jasper Monroe Wapello Taylor Michigan--		9,170,000
	Great Basin	Saginaw Bay *Jackson *Cedar Grand *Owosso	Saginaw Bay	1,440,000

COAL FIELDS OF THE UNITED STATES—(Continued)
 Principal Coal Producing States and Districts in Each.

State	Field	Districts	Trade Names	Coal Production 1920, net tons.
Washington	Puget Sound	Skagit- Whatcom, Anthracite New Castle—Issaquah- Carbonado—Wilkeson- Grand Ridge— Renton Green River Snoqualmie— Bayne— Burnett Gale Creek— Wilkeson— Carbon Hill— Fairfax— Roslyn— Beekman— Cle Elum— Southern, Lewis— Thurston— Cowlitz County—	Centralia— Ladd— Cowlitz— (*) Non producing	8,760,000

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